Zygomatic Implants

Optimization and Innovation

James Chow
Editor

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Foreword

There is no question that the concept of osseointegration revolutionized the practice of implant dentistry in terms of functional predictability and longevity. The subsequent introduction of the zygoma implant in 1989 further enhanced the available options for the upper jaw and offered significant improvements in the quality-of-life potential for patients with maxillary compromise.

The very first zygoma fixtures were installed for a patient diagnosed with severe seizures after an accident in his youth. He lost teeth and major parts of the maxilla because of extreme bite forces which were impossible to control. There was not enough bone left in his jaw for installing regular titanium fixtures, and because of major health problems a bone graft procedure was not an alternative. Sufficient bone volume was present only in the zygoma region, and two fixtures of 30 mm length were placed. These two fixtures provided the support for an eventual and revolutionary obturator prosthesis which restored the patient to a near-normal functional state. In 1990, a further five patients were treated with zygoma fixtures, four of whom received one zygoma fixture on each side and one patient received a single zygoma fixture. All five patients received regular titanium implants as well as the zygoma fixtures.

Since that time, the evolution of this concept has found application in a wide variety of maxillary presentations, ranging in the conventional patient from augmentation of needed posterior support to the elimination of the need for sinus grafting when that is the expressed desire of the patient. Combining two implants per side, the "quad approach" has likewise almost eliminated the need for large block grafts donor site from the ilium and is today considered the state-of-the-science treatment for the severe atrophic maxilla.

Whether deficient due to trauma, congenital syndromes, or neoplastic disease, the patient with maxillary defect today may be the most significant beneficiary of the modern use of the zygoma implant. Maxillectomy patients, especially those with an edentulous partial arch, classically struggle with impossibly difficult retention and obturation requirements. Today, these individuals can enjoy normalized speech, deglutition, and mastication as a result of the support a zygoma/conventional implant combination can provide. This concept can be extended to those with combined facial defects by using highly imaginative zygoma, and smaller implant combinations to support intra-oral and facial prosthetics without the need for adhesives.

This book shows the evolution of the zygoma procedure according to the osseointegration concept, presented by several independent professionals from all over the world. Today, we have seen great success with zygoma implants, and they have been subsequently refined for improved clinical function. This is indeed a most timely book that is strongly recommended for anyone interested in this particular implant technology which can increase quality of life for a patient category otherwise difficult to help.

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Introduction

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The zygomatic implant is a milestone of progress in the genesis of oral implantology. This book presents the state of the art and science in the matured application and clinical practice of zygoma-anchored rehabilitation, some 30 years following the introductory Brånemark Zygoma protocol.

Before market release, the original protocol was evaluated in a controlled, international, prospective, multicentre clinical trial in 16 participating centres geographically widespread, including our centre in Perth, Australia [1]. Very encouraging early results were published in 2004. Subsequently, ongoing software and hardware developments have significantly simplified and improved procedures and protocols together with expanded applications. Contribution to these developments has been worldwide and is further reflected by the international spread of authors of this textbook.

The zygomatic implant largely remains a treatment provided by surgical and prosthodontic specialists. It is classically indicated for the treatment of atrophic maxilla, but can be advantageously used for a variety of other residual anatomical defects. Chantel Malevez, one of P-I Brånemark's earliest international collaborators, presents a systematic overview and global perspective of the zygomatic implant after 20 years of collaborative international practice. This historical experience provides a sound basis for the subsequent improvement, modifications and expanded applications that we see presented throughout this book.

The original Brånemark system zygoma implant had a machined surface with the angulated head of the implant perforated so that the standard components for the Brånemark system implants with regular platform could be used. This open abutment screw orifice concerned many clinicians with respect to its micro-leakage potential and possible inflammatory response in the adjacent soft tissues. In 2004, the Brånemark system Zygoma TiUnite™ implant was introduced, followed by the

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Nobel Zygoma™ implant in 2016. The head of the TiUnite™ surface implant is non-perforated and a specific zygoma implant abutment is required. These hardware improvements were enthusiastically welcomed by most clinicians. Another early days concern was the issue of 'implant flexibility', whereby lateral pressure on the unconnected implant, in some cases, elicited a degree of lateral flexibility perceived as movement as a result of apical bone flexion related to the long lever arm of the implant integrated only into the apical bone. Prosthetic connection eliminated this concern because of the bilateral stability afforded by the prosthesis. Consequently, subsequent surface modification, implant design and application of various surgical design protocols have largely eliminated this concern.

Bernard Koong reviews imaging for zygomatic implants. Various methods are compared and contrasted. Currently, the CBCT examination is the most effective procedure, together with export of the DICOM files for segmentation and simulation. In conjunction with dental implant planning software, the DICOM files can be segmented for 3D reconstruction. Currently available software programs have different scanning protocols and an appropriate radiographic guide or template should be fabricated according to the specific protocol prior to the CBCT examination.

Edward Hui and Raymond Chow discuss the digital workflow for zygomatic implants from the diagnosis and treatment planning stage, surgical procedures and prosthetic connection. Following segmentation of the DICOM files for 3D reconstruction, the surgical phase of treatment can be simulated with implants placed and positioned according to a prosthetic-driven approach to ensure final aesthetic and functional outcome. In selected cases and using applicable software, generated surgical guides can be produced by 3D printing for pilot drills and possibly fully guided implant placement. The final prosthetic outcome is controlled by the entry point of the zygomatic implant as well as maximising the utilisation of available bone for adequate anchorage. Current advancements and improved digital technology in implant dentistry have significantly enhanced the clinician's ability to provide quality care at a higher level and with improved predictability. Accordingly, improvements have been introduced in the area of surgical placement of zygomatic implants beginning with free-hand surgical placement, progressing to guided surgical placement and more recently, navigational placement. Specific areas wherein the clinician must become properly trained in order to take full advantage of the improved technologies and advanced techniques so that they may provide a higher standard of care are discussed. Specific areas focusing on the functional and aesthetic aspects of treatment are emphasised.

The middle one-third of this book is concerned with alternative surgical approaches for zygomatic implant placement. Following on from the Brånemark protocol used in the original multicentre study [1], a number of conceptual improvements have been introduced to simplify treatment and minimise interference with the maxillary sinus to avoid sinus-related complications while enhancing the biomechanical outcome.

The Zygoma Anatomy Guided Approach (ZAGA) developed by Carlos Aparicio is a one-stage procedure for immediate loading. This ZAGA classification takes into account prosthetic-driven implant placement and the degree of concavity of the anterior maxillary wall. Accordingly, five different anatomical possibilities exist that influence the possible trajectory of zygomatic implants. Research has shown that success rates of the ZAGA concept are comparable to the original Brånemark protocol, but with improved prosthetic outcome and reduced incidence of sinus complications.

The extra maxillary zygomatic implant, developed and described by Paulo Malo, aims to keep the zygomatic implant external to the maxillary sinus, irrespective of the anatomy. This procedure utilises an implant specifically designed to eliminate threads on the coronal part, with increased diameter of the apical section and either a 0° or 45° implant head. The threadless part of the implant does not penetrate the crestal residual alveolar ridge. This surgical procedure provides good visualisation of the osteotomy and simplifies easy positioning of the implant head buccal to the crest of the ridge. This prosthetic-driven implant position will place the head of the implant beneath the proposed occlusal surface and comparatively reduce the bulk of the prosthesis buccolingually, improving speech and facilitating plaque control.

The original Brånemark protocol for the full-arch zygoma case utilised a zygoma implant bilaterally with standard implants placed anteriorly. The quad zygoma, as discussed by Ruben Davo, is indicated where the anterior maxillary residual alveolar bone is diminished and, conceptually, the situation is managed by the placement of four zygomatic implants, two on each side posteriorly with effectively an anterior prosthetic cantilever. Biomechanically, it is critical to locate the optimal position for the apical section of the implants where maximum bone-to-implant contact can be achieved. This is fundamentally important. Conversely, many clinicians will try to include even limited anchorage potential anteriorly to offset the anterior cantilever challenge. However, this is often contemplated to ensure the clinicians own sense of security rather than what may be biomechanically acceptable from a scientific point of view.

Yiqun Wu and Chris Butterworth describe the application of the zygomatic implant in the rehabilitation of significant developmental and surgical defects. Residual defects in congenital conditions and oncology resections are highly variable and individually often compromised. Implant-anchored restorations are dependant on the establishment of anchorage points provided by implants placed wherever potentially suitable bone exists and investing soft tissues are manageable. The zygomatic implant is advantageous in a multitude of residual bone sites and can be used in unconventional locations with variable trajectories as dictated by available bone. All of the strategies and protocols discussed earlier in this book may be applicable in principle and with modification for these challenging and often complex situations. Their chapter contributions highlight the requirements, strategies and solutions available to restore a functional capability and give these deserving patients an improved quality of life.

Co-authors Andrew Dawood and James Chow have both contributed very significantly to the advancement of hardware and software aspects of implant therapy in general and the zygomatic implant in particular. Their chapter on ‘Optimisation and Innovation in Zygomatic Implants’ reviews current research and development in osseointegration along with advances in technology, materials and biomechanical science. Their individual and collaborative expertise, foresight, investment and propagation of development underscore their many and varied contributions to this area of treatment.

The book closes with a detailed consideration of success criteria by Carlos Aparicio, Roberto López-Piriz and Thomas Albrektsson. Historically, success criteria as applicable to dental implants have been somewhat controversial and variable and not necessarily relevant to the zygomatic implant. Accordingly, this chapter gives the clinician and researcher a rationalised and scientific basis to evaluate treatment outcome of an implant which is significantly different in design and application from conventional dental implants.

This climax of opinion and expertise reflects the content of the book and discusses the strengths and weaknesses of the current direction together with possible future projections. In conclusion, we see in this book a number of different approaches to the placement and utilisation of the zygomatic implant. This variability of concept and protocol may be of concern to newcomers to the field because they may feel more comfortable being presented with and adopting a single protocol. Conversely, some experienced clinicians may only adopt a single protocol with a somewhat closed mind to other possibilities. Such paradigm entrenchment may have been subtly inculcated through prolonged education which results in difficulty to convince them that there can be other, different, possibly advantageous worldviews from their own. Consequently, the entrenched view may be so deep that disrupting it or even acknowledging it is perceived as a threat. This phenomenon is a reflection of 'confirmation bias', which refers to the tendency to look for information that only confirms what we believe, to accept facts that only strengthen our preferred explanation, and to dismiss data that challenges what we already accept as truth [2]. In closing, therefore, it is respectfully suggested that experts in the field, moderately experienced practitioners and most importantly, newcomers to the zygomatic implant, read and digest this book as a whole and not just view it to satisfy a personal confirmation bias.

Accordingly, it is the strength of this book that it challenges the reader to look again and to think again. Whilst the development of the zygomatic implant has been a steep and rewarding learning curve, this book will serve as a fundamental reference and a window to the future.

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Zygomatic Implants After 20 Years: Systematic Overview and Global Perspective

Chantal Malevez

Introduction

Despite the fact that standard endosseous implants have been used for the treatment of total and partial edentulism due to the discovery of the osseointegration phenomenon, restrictions have appeared due to the lack of bone in certain clinical situations such as the posterior maxilla where bone height may be less than 1 mm and also in the anterior region corresponding to classes 4, 5 and 6 of Cawood and Howell [1] or the similar classification of Lekholm and Zarb [2].

Bone augmentation procedures, be they onlay or inlay grafting with or without Lefort I osteotomies [3], have been proposed and used. In addition, synthetic biomaterials and angled implants in the parasinus region [4], implants in pterygoid apophysis [5], and short and wide implants [6] are available options to address maxillary bone deficiency.

Sinus grafting was developed by Boyne in the 1980s [7].

These augmentation techniques are reliable and scientifically documented even in long-term follow-up [8]. However, they are time-consuming, not cost-effective, and need invasive surgery with possible associated morbidity. Furthermore, the duration of treatment is extended and can be uncomfortable for the patients who are not allowed to wear a removable prosthesis during the healing time and have to undergo two surgeries. With regard to short implants, these are often placed in bone with lower density and failure rates are higher with shorter implants [9].

In the 1980s, P-I Brånemark's concern for patients suffering from atrophic jaws, whom he referred to as handicapped patients, led to his conception of the idea that implants could find sufficient anchorage in the zygoma, even though their anchorage was quite far from the maxilla. He was accustomed to using zygoma implants

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for anchorage in hemimaxillectomy cases [10, 11] and adapted this concept to totally edentulous patients with very atrophic posterior maxillae [12]. These zygoma implants, when combined with standard implants placed in the anterior maxilla, would be able to support masticatory forces transmitted through a fixed implant complete denture prosthesis screwed to the implants and employing cross-arch stabilization. The first zygomatic implants were straight, but according to prosthetic requests, they were transformed into angulated implants with a 45° angulation at the intraoral head of the implant. This 45° angulation corresponds to the angulation of the zygoma and the maxilla and through this degree of angulation, the collar of the implant is more or less perpendicular to the occlusal plane and facilitates prosthetic reconstruction. The implant head that will be subsequently restored is a Brånemark system external hexagon.

In 1997, the protocol was spread all over the world with a first multicenter study involving 16 centers and the results were published after 1 and 3 years postplacement [13, 14]. Results were overwhelmingly positive.

This open prospective study, in which patients have been consecutively included during one and a half years and followed up for 3 years after prosthetic insertion, was conducted from December 1997 to January 2000. Seventy-six patients received 420 implants including 145 zygomatic fixtures. The cumulative survival rate (CSR) for the zygomatic fixtures was 97% after 1 year and 96.3% after 3 years.

The protocol included a two-stage surgery with the placement of the implants and covered by the soft tissues, and a reopening 6 months later with placement of the abutments and placement of a screw-retained fixed prosthesis. The connection at the abutment level was simply that of a regular platform implant of the Brånemark system. Since this first multi-center study, additional papers have been published reporting success rates up to 100% and with up to 10 years of follow-up [15].

With the evolution of the general concepts in implant-based therapy and the appearance of immediate loading, these same concepts were applied to zygoma implant therapy around 2004. The first paper was published by Chow et al. in 2006 [16] describing a short series of patients treated with immediate placement of prostheses on the implants.

In addition, oral surgeons were confronted with more cases of severe atrophy of the premaxillary region and the impossibility to place standard implants in this site. A protocol to place four zygomatic implants, widely known as the "quad zygoma," grew from this clinical need and its use was taken up quickly [17, 18] with the four implants being immediately loaded.

The Anatomy of the Zygomatic Bone

The anatomy of the zygoma was investigated with regard to volume, distance from the maxilla, bone quality and quantity, external convexity, and internal concavity to allow for the best insertion site and path of the implants [19–21]. In summary, the zygoma bone presents trabecular bone useful for osseointegration and strong cortical bone useful for primary stabilization. The sinus wall was investigated and a classification has been elaborated by C. Aparicio [22]. Effectively, the sinus wall can be flat or concave. Due to these particularities, the classification system of ZAGA 1, 2, 3, 4 was established.

The zygoma was also analyzed in terms of pillars and buttresses by Prado et al. [23, 24] in a review including bone strain studies and finite element models (FEM) in human and nonhuman primates. The authors concluded that the concept of a zygomatic "pillar" does not describe well the behavior of the human skeleton during biting because, during biting, especially in the molar region, the zygomatic complex is first loaded in bending and shear.

Brunski [25] estimated, in a chapter evaluating the biomechanics of tilted implants including zygoma implants, that the advantage of tilted implants is to reduce the length of prosthetic cantilevers, but that the stresses and strains will be larger with tilted implants than with straight implants. The specific benefit, therefore, of zygoma implants is that the anchorage is not at the maxillary level but in the zygoma.

Freedman [26, 27] used FEM for cases treated with two or four zygomatic implants and demonstrated that the masticatory load applied to the zygoma was diminished by the presence of adequate buccal bone around the collar of the implants.

Wen et al. [28], having analyzed three different surgical techniques, the ad modum Brånemark, the exteriorized one, as well as the extra maxillary one, confirmed that the exteriorized one appears most appropriate for the severely atrophic edentulous maxilla.

Imaging

Although P-I Brånemark conceived the placement of the zygomatic implant using only orthopantogram (OPG) or tomography Scanora type imaging, today, with the spiral CT scan and cone beam computed tomography (CBCT), irradiation doses are diminished and it is desirable to utilize these imaging modalities to plan zygoma therapy. In 1998, Verstreken et al. developed a program in 2-D and 3-D on which implants could be inserted. As described by Verstreken et al. [29], with the Nobel clinician program as well as with others, it is possible to virtually position zygoma implants during the planning stage relative to available bone and desired prosthesis location. The advantage of this program is to be prepared before surgery regarding implant length to be utilized as well as to better aware of implant positioning. This will be developed in another chapter.

The Surgery

In 1997, the original protocol consisted of the following:

After an incision on the palatal side of the maxillary crest, the soft tissue is reflected up to the level of the zygoma. A little window in the sinus wall allows for displacement of the sinus membrane inside the sinus and with four different drills, the path of the zygoma implant is created at the level of the first or second premolar. Then, the machined self-tapping implant is inserted and stabilized in the superior cortex of the zygoma with careful focus to ensure primary stability of the implant. This protocol led to the complete trans-sinus position of a zygomatic implant. Sinuscopy was performed by Petruson [30] and published for 15 cases showing that sinusitis was not a systematic complication and that the sinus could remain healthy, findings further confirmed by Davó et al. [31]. The collar of the implant covered by a cover screw was completely buried under the soft tissues and, after 6 months, soft issues were reopened at the level of the zygomatic collar and abutments installed together with a fixed prosthesis. This protocol was followed by many surgeons with a success rate up to 100% [32, 33].

Over time, a better understanding and appreciation of the anatomy of the anterior sinus wall have been gained [22] as sustained efforts have taken place to improve prosthetic outcomes. Further, initial modification of the surgical protocol took place [34–36] so that zygoma implants emerged more on the maxillary crest in an exteriorized position (meaning the implants were no longer introduced into the sinus) [37], and, then later, in an extramaxillary position providing easier prosthetic reconstructions while avoiding the need to enter the sinus. Avoiding entry into the sinus drastically reduced problems with sinusitis that can cause oroantral fistulae and, therefore, possibly the need to remove the zygomatic implant. All these new techniques and anatomical precisions will be provided in other chapters of this book.

Relevant to these surgical changes, an interesting thesis [26, 27] with a finite element analysis showed that it was important to keep some buccal bone around the implants in order to diminish the masticatory loads on the zygoma.

The development of the quad zygoma protocol could take place, thanks to improved imaging and especially to a program like Nobel clinician that allows for the positioning of implants in 2D and 3D images. Van Steenberghe et al. [20] published a study with cadaver's heads and patients showing that the anteroposterior width of the zygoma that permitted the insertion of two zygomatic implants per zygoma would need to be 20 mm. Even if this surgery is more demanding, more and more patients can be treated with four zygoma implants. This procedure completely restores their quality of life [17].

Prosthetics

Since the traditional immediate loading protocol was successfully adapted to use with zygomatic implants, a provisional prosthesis made of acrylic (and that can be an adaptation of the removable prosthesis of the patient where the palatal shelf is removed) is screw-retained to the implants on the day of the surgery.

Four months later, a fixed prosthesis made of either titanium and acrylic teeth (resin hybrid) or a ceramic prosthesis is screwed onto the implants. Some practitioners prefer removable prosthesis adapted on a bar screwed on to the implants.

Literature Review

In the initial years after 1997, most scientific publications concerning the zygoma spoke about zygoma fractures and mini plates. The first papers concerning zygomatic implants for totally edentulous patients were published in 2000 by Stevenson et al. [38] and Higuchi [39]. Today, more than 400 publications are found on PubMed/Medline including reviews and meta-analyses. Some of these reviews concern the surgical steps [40]. Others led to the potential for meta-analyses, but the inclusion and exclusion criteria are not always clear and could lead to bias. The advantage of these reviews for the readers is the compilation of many articles that could be tedious to read. But are these reviews a summary of evidence-based medicine or dentistry? For example, case reports are usually excluded, but the case report that describes an infrequent but significant complication should be noticed in a review of complications. Moreover, one systematic review selected 751 files [41] on the basis of abstracts. After filtering, 313 abstracts were selected for reading which led to the full text of 42 publications being read. Based on the eligibility criteria, only 25 of the 42 articles were included in the final review. Do these 25 papers give a true statistical analysis of the method and the results? Of note, if inclusion criteria were that a 10-year follow-up be required, there will be only one paper according to this criterion [42]. Should this single paper be credible and considered as significant?

However, different reviews have been analyzed by the author of this chapter.

Sharma and Rahul [40], in April 2013, conducted a systematic review on zygomatic implants after a PubMed search and limited to papers published in English. There is no information about the number of papers reviewed and no description of the inclusion or exclusion criteria. The authors describe zygomatic implant design, anatomic considerations, surgical considerations, and prosthetic rehabilitation. They concluded that the zygomatic implant therapy appears to be a promising development in implant technology.

In 2012, Candel-Marti et al. [43] reviewed indications for treatment, number of patients, number of implants, length, and diameter of the implants, surgical technique, prosthetic rehabilitation, success rate, complications, and patient satisfaction. Despite the fact that the number of reviewed papers was not indicated in the abstract and that the author of this chapter could not find publications in 1987, they included 16 studies with an impressive number of zygomatic implants (941 placed in 486 patients between 1987 and 2010). The authors concluded that zygomatic implants have a high success rate (89–100% with delayed loading and 96.37–100% with immediate loading) and may be a suitable alternative to other treatment protocols for the atrophic maxilla.

In 2013, Esposito and Worthington [44] raised a challenging question because they did not identify any RCT investigating whether zygomatic implants offer some advantages over alternative techniques such as bone augmentation or sinus augmentation with bone or biomaterials.

In 2014, Goiato et al. [41] published a systematic review evaluating clinical studies published between 2000 and 2012 on the follow-up survival of zygomatic implants.

As mentioned before, from a database search on 751 titles, only 25 titles were considered as clinically relevant and were included. One thousand five hundred and forty-one zygomatic implants were inserted with 33 implant removals. Interestingly, failures occurred generally during the first year and were related to recurrent acute and chronic sinusitis. However, after 36 months of follow-up, the survival rate was 97.86%.

In 2015, Wang et al. [45] published a review based exclusively on the use of four zygomatic implants. As far as the author of this chapter knows, it is the only study about four zygomatic implants, the survival of the implants being the primary outcome assessed with complications and quality of life also evaluated. The mean implant survival rate was 96.7% and the authors concluded that four zygomatic implants in severely atrophic maxillae offer a reliable treatment option.

In 2017, Tuminelli et al. [46] conducted a systematic review of implant survival, prosthesis survival, and potential complications while focusing on immediate loading protocols. From 236 titles, 38 articles were included in this review and the authors concluded that immediate loading is a reliable alternative to delayed loading for the treatment of atrophic maxilla.

In 2018, Aboul-Hosn Centenero [47] et al. published an interesting paper where survival rates of two zygomatic implants combined with standard implants in the anterior maxillae were compared to quad zygoma therapy outcomes. This is the first paper directly comparing the two protocols and showed no difference between the protocols with regard to implant survival. Clearly, the data analysis showed comparable results for the quad zygoma protocol compared to the two zygomas plus standard implants.

Concerning complications with zygomatic implants, two interesting reviews have been published. Chrcanovic et al. first published their findings regarding complications in 2013 and followed with a thorough update in 2016 [48, 49]. Inclusion criteria consisted of clinical human studies with patients receiving zygomatic implant therapy and subjects could be totally or partially edentulous or have had surgery for cancer. Clinical trials, cross-sectional studies, cohort studies, case-and-control studies, and case series were considered and implant failure represented by complete loss of the implant. One thousand four hundred and fourteen records were obtained from which 68 were included in qualitative and quantitative analysis. A total of 4556 zygomatic implants placed in 2161 patients were included with a total of 103 failures from 68 studies.

Specific results were as follows:

- The 12-year cumulative survival rate was 95.21%.
- Most failures appeared within the 6-month postsurgical period.
- Some studies (n = 26) evaluated immediate loading and showed a statistically lower zygomatic implant failure rate than studies (n = 34) evaluating delayed loading protocols (P = 0.003).
- Studies (n = 5) evaluating zygomatic implants for the rehabilitation of patients after maxillary resections presented lower survival rates.
- Postoperative complications with zygomatic implants can be:

- Sinusitis: 2.4% (95% confidence interval [CI], 1.8–3.0). Although sinusitis may appear early, it has also been observed long after implant placement.
- Soft tissue infection: 2.0% (95% CI, 1.2–2.8);
- Paresthesia: 1.0% (95% CI, 0.5–1.4);
- Oroantral fistula: 0.4% (95% CI, 0.1–0.6).

However, complications may be underestimated because many studies failed to mention the prevalence of these complications.

In summary, Chrcanovic et al. concluded that zygomatic implants have a high survival rate after 5 years, and that the number of complications is quite low.

In 2016, Molinero-Mourelle et al. [50], through a PubMed search along with a manual search yielding 455 studies, finally selected 14 articles for further in-depth review. Despite the fact that case reports were excluded and the exclusion criteria were quite severe, the advantage of this review is that complications are reviewed and that the incidence of complications is quite low. Although complication rate and type can be influenced by surgical protocol, sinusitis is considered the most frequent complication with a prevalence of 3.9%. In cases where implants are placed bilaterally, sinusitis may affect one sinus and not the other one.

Non-osseointegrated implants appear with a 2.9% frequency. The absence or loss of osseointegration can be due to overheating of the zygomatic bone, infection, insufficient bone quantity/volume, lack of primary stability, or incorrect application of immediate loading. Local infection shows a prevalence of 4%. Fistula at the maxillary level occurs with a frequency of 2%, and paresthesia has a frequency of 1.6%.

Bruising is not always mentioned by the authors because it seems to be a regular complication of implant placement and it usually disappears without consequences. Nevertheless, it should be noted that the frequency of bruising is 3.9%. Labial laceration can be due to an absence of protection during the drilling and is not well documented. Some studies do not mention any kind of complications.

Randomized Studies

As noted by Esposito and Worthington in 2013 [44], there was an urgent need for a randomized study concerning zygomatic implants. A proposition was raised in 2014 to compare the advantages and success rates of two rehabilitation procedures of the very atrophic maxilla using zygomatic implants with standard implants or quad zygoma therapy versus sinus lifts with biomaterials.

The study was conducted by Esposito et al. [51] in a multicenter study with a publication reporting 4-month findings (by Esposito) and then reporting 12-month findings (by Davo et al.). Results suggest that despite the fact that more complications are described with the placement of zygomatic implants, a more favorable outcome appears with zygomatic implants in terms of survival rates since a smaller number of implant and prosthesis failures occurred with zygomatic implants. Of course, longer follow-up is needed, but it is already known that the complications except sinusitis occur in the first months postoperatively. Therefore, it is anticipated that the initial promising results with zygoma implants will ensue over time [52].

Conclusions

Extensively developed over the past 20 years, the zygoma concept conceived by P-I Brånemark for the totally edentulous patient without discontinuity of the maxilla, may today be considered the treatment of choice for the significantly atrophic maxilla due to improvement in quality of life and lower costs, shorter time for rehabilitation and less surgery and prosthodontic work needed [53]. Scientific evidence demonstrates that the technique is reliable and predictable. For the clinician, excellent clinical expertise with a good knowledge of the anatomy in three dimensions is necessary, along with an understanding of the physiology of the sinus and the biomechanics of the prosthetic reconstruction. Even if standard implants and zygoma implants share the commonality of an external hexagon restorative platform, the anchorage mechanism is fundamentally different. The primary stability of zygoma implants is mandatory and careful attention to establish a harmonious occlusion is a key factor in the success of zygoma implant-based therapy. Future improvements are likely, given the possibilities afforded by guided surgery and navigation.

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Diagnostic Imaging for Zygomatic Implants

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Pre-implant diagnostic imaging is essential for the correct placement of zygomatic implants. The limitations of two-dimensional (2D) radiography and tomographic techniques including the panoramic radiograph are well known. These techniques are clearly insufficient for the precise planning of zygomatic implants. The application of volumetric imaging in the planning of alveolar implants is well accepted [1–7]. It is even more critical that volumetric imaging be employed for zygomatic implant planning. The benefits of the three-dimensional nature of volumetric techniques in relation to designing the location and orientation of zygomatic implants are obvious and volumetric data sets may be used for virtual planning and fabrication of computer-generated surgical guides [2, 4, 5, 7, 8]. Pre-surgical identification of diseases related to the maxillary-zygomatic complex is of importance and more likely to be missed or not well visualised with 2D and/or panoramic radiography.

Volumetric Imaging Modalities

CBCT uses a cone- or pyramidal-shaped divergent X-ray beam. Multiple sequential projections are captured by an area detector on the opposite side of a rotating gantry [1, 9, 10]. Another term also used for this modality is cone beam volumetric tomography.

MDCT employs a collimated fan-shaped X-ray beam that rotates helically around the patient. A second collimator related to rows of solid-state detectors reduces the scattered photons. Several other terms are also used for this modality, including multislice CT.

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Image Quality

An advantage of CBCT is the high resolution achieved. Some scanners are able to produce isotropic 3D voxel sizes potentially as small as 0.076 mm [1, 2, 10]. However, the extremely high-resolution scans are limited to small field of view (FOV) scans. The planning of zygoma implants with CBCT requires larger FOVs, which are typically associated with voxels much larger than 0.076 mm, closer to those of MDCT.

In addition, CBCT image resolution in practice ranges widely, potentially less than MDCT [11]. Orofacial CBCT is subject to more detrimental effects on image quality than MDCT, including:

- Noise
  - CBCT scans are associated with increased noise compared to MDCT. The amount of Compton's scattering is proportional to the volume of tissues in the X-ray beam [1, 9] and CBCT scans for zygoma implants require relatively large FOVs.
- Signal-to-Noise Ratio
  - CBCT scans are associated with lower signal-to-noise ratios [1, 9, 10, 12]. The substantially higher signal-to-noise ratio associated with MDCT [1, 8, 11] contributes to improved image quality.
- Beam Hardening
  - This is a common issue with orofacial CBCT [1, 3, 9, 10, 12, 13] and not usually associated with MDCT studies of the orofacial structures. This results in the appearance of streaks (Figs. 1 and 2), decreasing image quality. The size and density of a patient's head contribute to the degree of beam hardening [1].
- Motion Artefact
  - This is a common problem with CBCT, as the scan times are generally substantially longer than with MDCT. Selection of a shorter CBCT scan time may reduce motion artefact [9, 13], but this reduces image quality.
  - In addition, the vast majority of orofacial CBCT scans are performed with a patient in an upright position and the head held with various devices. MDCT scans are performed with a patient in a supine position and his/her head is at rest on the table, which facilitates a patient keeping still during the scan.
- Cone Beam Effect
  - The peripheries of CBCT scans are subject to more image distortion, streaking artefacts and greater noise [9, 10]. This can be an issue when the zygomas are at the periphery of the FOV, particularly when a more limited FOV machine is employed and/or if a patient is larger. This is not an issue with MDCT.

The compromises in image quality associated with CBCT discussed above, when more severe or if there is a combination of these factors present, potentially compromise the accuracy of measurements made with a particular scan. Therefore, the potential impact on accurate interpretation of these studies should be