Identification of the Pathway and Appropriate Use of Four Zygomatic Implants in the Atrophic Maxilla: A Cross-Sectional Study

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Purpose: This cross-sectional study aimed to identify and characterize the pathway for appropriate placement of four zygomatic implants in the severely atrophic maxilla and to group the anatomical variations of the osteotomy trajectory for anterior zygomatic implants. ***Materials and Methods:*** CBCT images of patients presenting indications for the use of four zygomatic implants to withstand a maxillary rehabilitation were reviewed. Cross-sectional planes corresponding to the implant trajectories, designed according to a zygoma anatomy-guided approach for implants placed in the anterior and posterior maxilla, were assessed separately. The relationship of the implant osteotomy trajectory with the correlated residual alveolar bone, nasal and sinus cavities, maxillary wall, and zygomatic bone anatomies was established. ***Results:*** The study population included 122 globally recruited patients, with 488 zygomatic implants, 244 of which had their starting point on the anterior incisor-canine area and 244 on the posterior premolar-molar area. The anatomy of the osteotomy path designed for the anterior implants ("A") was named and grouped into five assemblies from zygomatic anatomy-guided ZAGA A-0 to A-4, representing 2.9%, 4.5%, 19.7%, 55.7%, and 17.2% of the studied sites. Percentages for posterior implant ("P") trajectories of the osteotomy were grouped and named as ZAGA P-0 to P-4, representing 5.7%, 10.2%, 8.2%, 18.4%, and 57.4% of the sites, respectively. Approximately 70% of the population presented anatomical intra-individual differences. ***Conclusion:*** The trajectory of the zygomatic implant followed different anatomical pathways depending on its coronal point being anteriorly or posteriorly located, which justifies a new zygoma anatomy-guided approach classification for anteriorly placed zygomatic implants. Topographic characteristics of the anatomical structures that are cut by an anterior oblique plane joining the lateral incisor-canine area to the zygomatic bone, representing the planned anterior osteotomy path in a quadruple-zygoma indication, have not been previously reported. Adaptation of surgical procedures and implant sections/designs to individual patients' anatomical characteristics is essential to reduce early and long-term complications. *Int J Oral Maxillofac Implants 2021;36:807–817. doi: 10.11607/jomi.8603*

Keywords: cross-sectional studies, maxillary atrophy, zygoma, zygoma anatomy-guided approach, zygomatic implants

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Rehabilitation of the severely atrophic maxilla using zygomatic implants has become widespread among dental specialists and a focus of increasing interest due to the aging population and willingness to preserve the quality of life. In two systematic reviews to assess the use of zygomatic implants for maxillary rehabilitation, survival rates of 96.7% over a 12-year period[1] and 97.9% after a 36-month follow-up[2] were reported. However, no clear data were provided on the frequency and type of complications, such as sinusitis or soft tissue dehiscence, and on the way survival was assessed. The results of randomized controlled trials comparing immediately loaded zygomatic implants to bone augmentation procedures showed statistically significantly fewer prosthetic failures, implant failures, and time needed to functional loading in the zygomatic implant group.[3,4] However, complications were significantly more common among patients rehabilitated with zygomatic implants, who showed an apparent increase in severe sinusitis over time. It may be speculated that the increased amount of sinusitis may be due to the use of the original intrasinus technique in 78% of the implants combined with the use of a rough threaded implant surface.

The original zygomatic Brånemark protocol for oral rehabilitation was designed for the placement of one implant on each zygoma, with its starting point at the first molar/second premolar zone, plus two to four anterior regular implants. According to the author, "the direction of the zygoma fixture was selected to provide optimal stability over prosthetic requirements."[5] In order to accomplish an intrasinus path in the presence of a concave maxillary wall, the implant head was located on the alveolar palatal side, leading to bulky prostheses. Several factors related to the zygoma implant passing through the palatal aspect of the alveolar bone to the sinus may induce maxillary rhinosinusitis as well as a clinical or subclinical oroantral communication issuing from the peri-implant sulcus. Risk factors may include a discrepancy between the osteotomy diameter and the implant diameter, history of periodontitis, inadequate oral hygiene, or peri-implant osteomyelitis, among others. The possibility for this event to occur would be in an inverse relationship to the sinus floor thickness. The sinus floor inflammatory response manifests as vague perialveolar and facial pain, without pain being elicited from loading the implant itself.[6] Antibiotics clear the infection, which eventually may return later. These findings have been reported by different authors together with a proposal for a systematic way to evaluate and report sinus status.[7–9]

To better understand the influence of anatomy on a prosthetically driven implant trajectory, the zygoma anatomy-guided approach (ZAGA) and classification were described by Aparicio.[10,11] Known as ZAGA classification, it recognizes the anatomical differences in the trajectory of a zygomatic implant placed from the posterior premolar/molar area during its alveolar and anterior maxillary wall path. Indeed, the classification was intended for describing anatomical differences in the double posterior zygomatic implant trajectory but not for anterior zygomatic implant placement as in the case of quadruple zygomatic implant placement. Based on the understanding of the zygoma anatomy-guided approach,[10,11] surgery is adapted to the patient's specific anatomical characteristics, so the implant path may be intrasinus, extrasinus, or intermediate using the maxillary wall as an additional source of anchorage. The approach aims for maximizing the primary stability of a prosthetically driven zygomatic implant, preventing late complications, such as oral-antral fistula and soft tissue recession/infection, which implies a conservative osteotomy at the coronal-alveolar, medial-maxillary wall, and apical-zygomatic level.

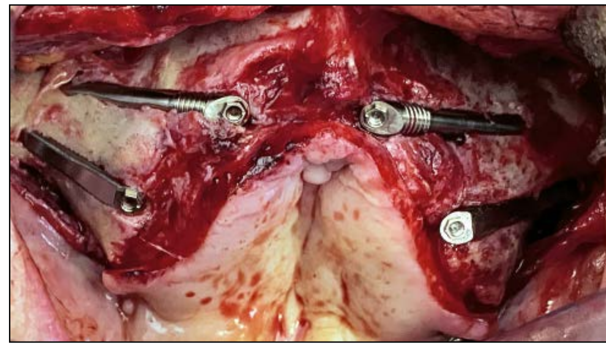


Fig 1 Clinical image of an extremely atrophic maxilla. Four implants have been anchored on the zygomatic bone. The anterior implants have a round circular section (Straumann ZAGA-Round, Straumann). The two posterior implants (Straumann ZAGA-Flat, Straumann) have a flat circumference arc section (in collaboration with Drs Ophir Fromovich and Guy Mclellan).

Currently, the indications for zygomatic implants have been broadened since they are used not only in cases of lack of bone in the posterior maxilla but also in clinical cases of extreme anterior and posterior maxillary atrophy. Then, four implants anchored in the zygomatic bone are placed[12–15] (Fig 1). In this new perspective, the indication for reaching zygomatic bone from the incisal/canine area cannot be extrapolated using an intranasal implant path, in the same manner as the intrasinus path that was prescribed in the original technique. The reduction of subnasal bone volume frequently forces the surgeon to choose an extranasal/extrasinus implant trajectory. New complications, such as soft tissue dehiscence and subsequent infection related to an eventual extramaxillary zygomatic implant position, have appeared and should be addressed.[7–9]

This cross-sectional study was conducted to identify the pathway for appropriate placement of four zygomatic implants in the severely atrophic maxilla, and to recognize and classify the anatomical characteristics of

Table 1 Goals of the Minimally Zygoma Anatomy-Guided Approach[10,11] (ZAGA) Osteotomy

Achieve maximal implant primary stability.
Accomplish a prosthetically driven implant trajectory, placing the implant head at the optimal dental position.
Preserve as much bone as possible at the maxillary wall and alveolar bone.
Maximize the bone-to-implant contact along the length of the whole implant. This includes alveolar, maxillary wall, and zygomatic bone.
Completely seal the osteotomy.
Protect the sinus integrity at the implant head/neck level to prevent late sinus-oral communication.
Prevent soft tissue dehiscence.

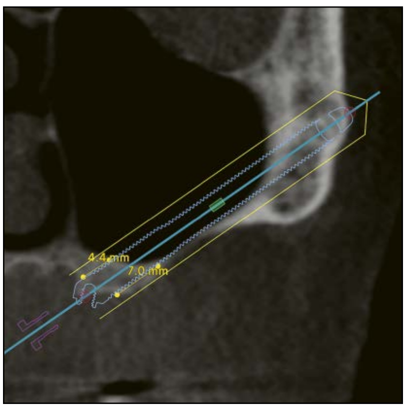


Fig 2a Radiographic simulation of intrasinus path indication using the DTX Studio implant from Nobel Biocare. The alveolar sinus floor thickness is > 4 mm, and appropriate residual alveolar architecture is present; a tunnel osteotomy has been virtually performed. Sinus entrance was prosthetically driven, regardless of maxillary wall anatomy and sinus lining integrity.

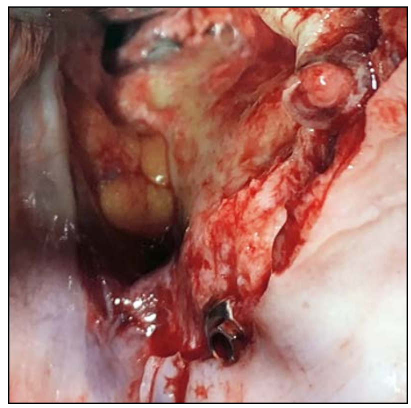


Fig 2b Clinical image of the planned zygomatic implant (Southern Implants, Zygan design) of Fig 2a, placed according to the zygoma anatomy-guided approach in type 0 anatomical features. More than 3 mm of sinus floor and adequate alveolar architecture were found; accordingly, a tunnel-shape osteotomy was performed. No slot or window antrostomy previous to implant placement was performed; sinus lining was deliberately pierced (in collaboration with Drs Virginia Aparicio and Asun Aréjula).

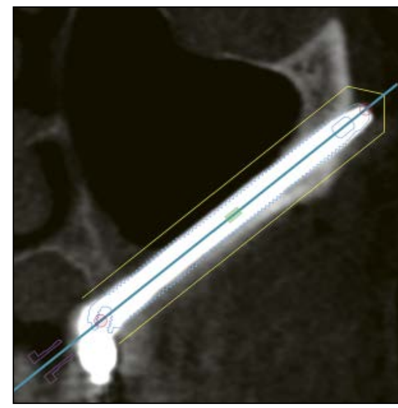


Fig 2c Postsurgical radiographic cut of the previous clinical image. The prosthetically driven circular "tunnel osteotomy" is entering the sinus through a 4-mm alveolar thickness in a zygoma anatomy-guided approach type 0.

the osteotomy trajectory designed for anterior zygomatic implants.

MATERIALS AND METHODS

This was a cross-sectional multicenter study in which CBCT images of patients undergoing implantation of four zygomatic implants for a fixed oral rehabilitation were reviewed. Radiologic criteria for the placement of four zygomatic implants was the presence of < 5 mm alveolar bone height/thickness in the anterior and posterior regions, making it impossible to place regular implants.[11] Patients were globally recruited at centers belonging to the ZAGA Centers Network (www.zagacenters.com).

Patient-related and environmental factors were not considered at the time of virtual planning. Zygomatic implant trajectories were planned using the DTX Studio Implant software (Nobel Biocare) and subsequently analyzed. Anterior implants were defined as those having their starting coronal point on the incisor-canine area, and the posterior implants as those emerging on the premolar-molar area. Virtual implant osteotomy trajectories were established using the zygoma anatomy-guided approach,[10,11] according to which the prosthetically driven zygomatic implant trajectory is adapted to the patient's anatomical characteristics, with the implant paths ranging from intrasinus to fully extramaxillary trajectories. The approach involves a minimally invasive osteotomy, the goals of which are shown in Table 1.

The volume and architecture of the alveolar/basal process and the anterior maxillary wall curvature were crucial factors for establishing the coronal implant position. When the bone architecture at the nasal/sinus floor level was considered sufficient to house the implant neck (that is, ≥ 4 mm high × 6 to 7 mm wide) in an adequate alveolar architecture, attempts were made to place the implant through it using a tunnel-shape

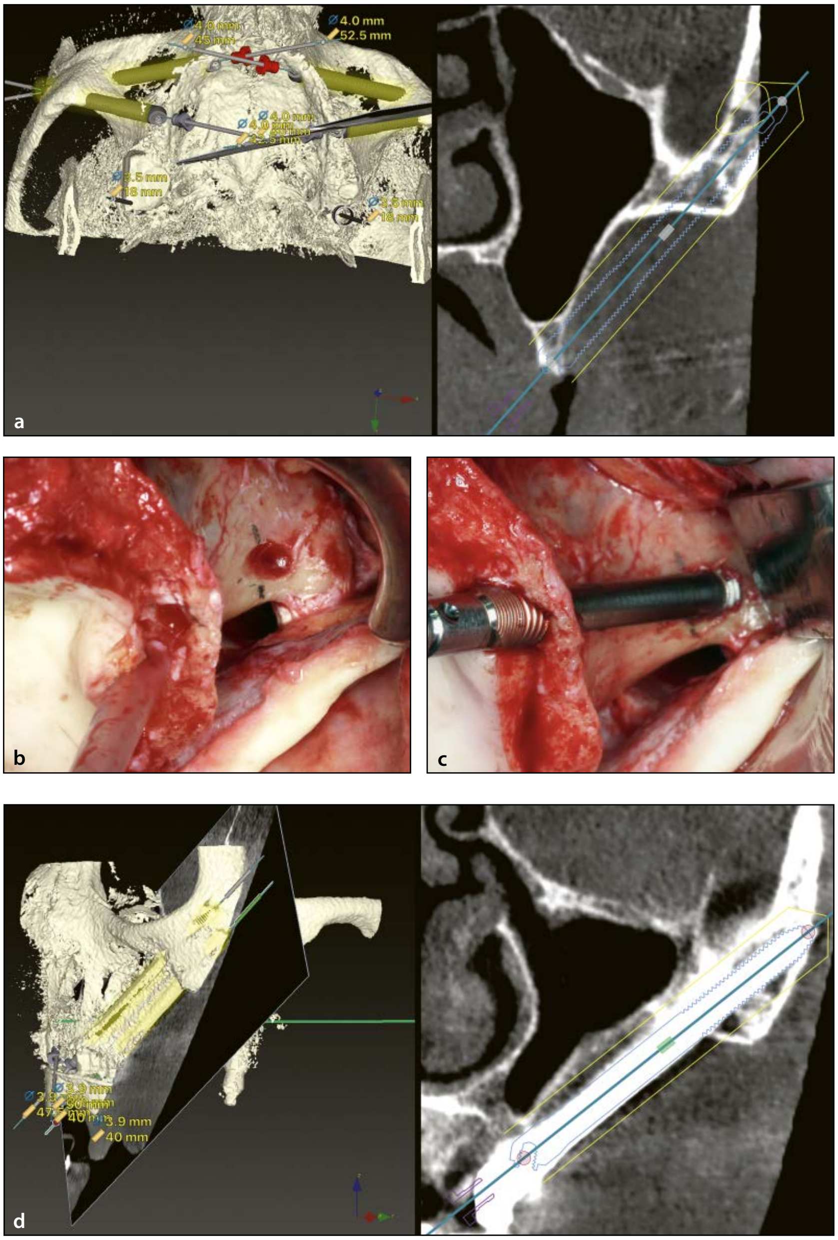


Fig 3a Radiographic cut on 2D and 3D visions representing a tunnel osteotomy virtually performed in the region of the left second premolar of a type 3 maxilla based on the zygoma anatomy-guided approach. The circular "tunnel osteotomy" is placed through the alveolar bone; sinus penetration will occur far from the critical coronal part of the implant. From the 3D view, a similar situation may be appreciated for implants in the position of the right and left canines. Simulation performed using the DTX Studio Implant software (Nobel Biocare).

Fig 3b Clinical image representing a tunnel osteotomy performed in a concave type 3 maxilla based on the zygoma anatomy-guided approach. The prosthetically driven circular "tunnel osteotomy" is placed through the alveolar bone. Alveolar bone remains have been respected to allow connective fibers to attach and prevent soft tissue dehiscence. Note that no slot or window osteotomy was necessary to accurately perform the zygoma osteotomy.

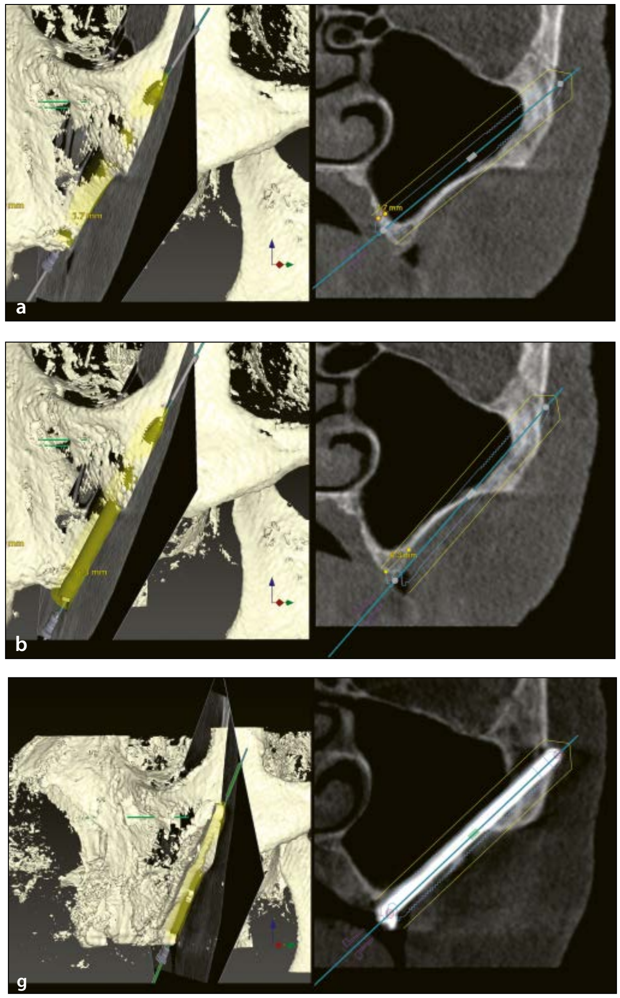
Fig 3c Clinical image shows how a circular implant section design (Straumann ZAGA-Round, Straumann) is sealing a "tunnel osteotomy" accomplished in a concave maxilla (in collaboration with Drs Peter and Madalina Simon).

Fig 3d Radiographic postoperative cut on 2D and 3D visions representing the final situation of the implant planned in Fig 3a. Maximum respect for alveolar bone remaining is mandatory to allow connective fibers to attach and prevent soft tissue dehiscence. Implant body is placed outside the sinus cavity.

osteotomy (Figs 2a to 2c). The term "tunnel osteotomy" referred to a circular osteotomy with lateral walls, floor, and roof. When a tunnel osteotomy was designed, the sinus membrane was perforated at the time of completion of the antrostomy, based on the rationale that implant positioning through an adequate amount of residual alveolar bone together with appropriate implant stability and design will provide enough bone-to-implant contact to achieve and maintain osseointegration as well as long-term antrum sealing. Moreover, since some alveolar bone buccal to the implant neck is maintained, the risk of late soft tissue complications will be minimized. A tunnel osteotomy implant path was also used in cases where the alveolar bone adopts a triangular, buccally inclined profile and the maxillary anterior wall is concave. In these cases, the circular osteotomy of the alveolar bone left the sinus lining intact, regardless of the maxillary wall curvature (Figs 3a to 3d).

In the event that there was inadequate residual bone architecture at the crestal level, instead of penetrating the antrum through a thin bone layer, the coronal osteotomy was buccally shifted to prevent future sinus or nasal-oral communication/fistula (Figs 4a to 4g). Implant beds were designed to be carved into buccal alveolar and maxillary wall bone with the limit of prioritization of sinus lining integrity maintenance. This osteotomy type, where lateral walls and floor but no roof may be found, was named "channel osteotomy."

When the volume and architecture of the alveolar/basal process forced for an implant path totally or



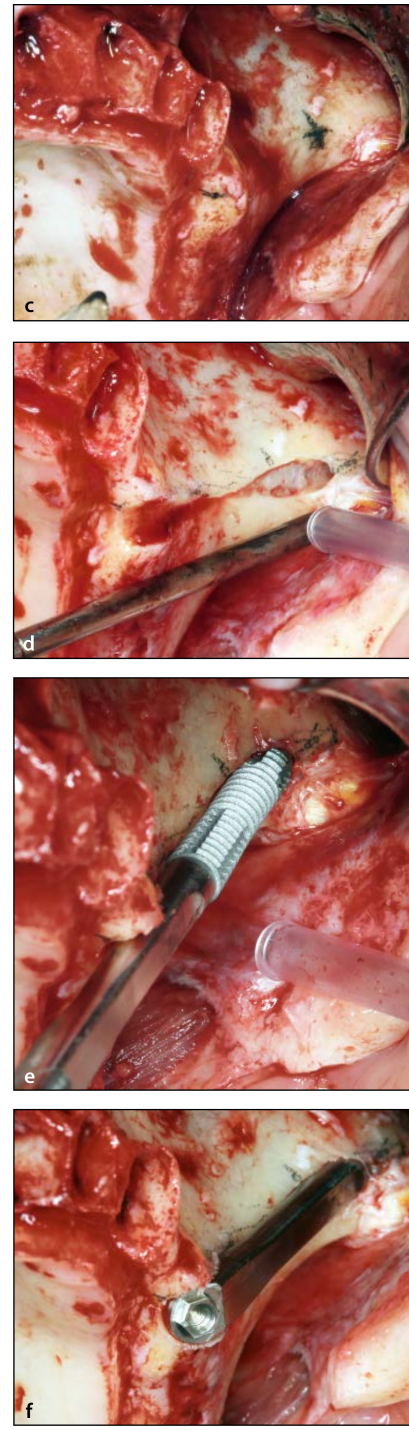


Fig 4a Radiographic cut on 2D and 3D visions representing a simulation for a classic intrasinus path using DTX Studio diagnosis software. The circular "tunnel osteotomy" is reaching the sinus through scarcely 2 mm of alveolar thickness. The possibility for development of late oral-antral fistula is considered.

Fig 4b Radiographic cut on 2D and 3D visions of the same patient and position of Fig 4a, showing a simulation for an extrasinus path of the implant. By buccal shifting of the osteotomy, the coronal bone-to-implant surface increases from 2 to 6 mm; antrostomy position is apically displaced, and sinus lining integrity is respected.

Fig 4c Clinical image showing how the surgeon is marking the coronal and the zygoma entrance points on the left second premolar/first molar position according to the virtual planning of Fig 4b.

Fig 4d Clinical image showing the minimally invasive "channel type" os- teotomy performed. Note the enlarged maxillary bone able to integrate with the implant. Also note the sinus lining integrity. Alveolar remains have been maintained to allow connective fibers to attach.

Fig 4e A conservative approach for the zygoma osteotomy is achieved by increasing the difference of diameters between the final drill and the implant. The final drill diameter was 2.8 mm. The implant tip goes from 2.4 to 3.4 mm. Self-cutting flutes are incorporated. In the apical section, diameter is increased from 3.4 to 3.9 mm, and new cutting flutes are present at its end. Primary stability is enhanced by the use of a tapered implant design (Straumann ZAGA-Flat, Straumann).

Fig 4f The implant in place is partially outside the bone envelope. The sinus has been respected. To diminish eventual vascular compression of the soft tissues, the implant has a flat profile. To reduce eventual bacterial contamination, the implant body is made of nonthreaded turned grade 4 titanium (Straumann ZAGA-Flat, Straumann). To allow for integration and bone sealing, the ZAGA Flat design of zygomatic implant has microthreads at the bony side of its neck (Fig 10b; in collaboration with Drs Peter and Madalina Simon).

Fig 4g Radiographic vision of the ZAGA Flat zygomatic implant placed according to the virtual planning of Fig 4b. The implant was adapted to the anatomy of an extremely resorbed maxilla. Maxillary sinus integrity is maintained 1 year after surgery. The superimposed virtual profile of a 4-mm diameter allows appreciation of the differences in diameter, both on the tip and body, between the new implant design and the classic designs.

Table 2 Factors Improving Primary Zygomatic Implant Stability

Careful maintenance of the initial drill direction without jiggling.
Underpreparation of the implant site, increasing the difference between final drill diameter and implant diameter.
Tangential osteotomy to engage more cortical zygomatic bone.
Osteotomy through four corticals at the zygomatic bone.
Preservation of maxillary wall structure. Do not discard maxillary bone by performing a "window" or sinus "slot" antrostomy previous to implant drilling.
Tapered zygomatic implant designs.

partially external to the maxillary wall, the antrostomy was usually established at the zygomatic process of the maxilla, inferior to the zygomatic-maxillary suture and separated as much as possible from the zygomatic critical zone, located where the implant contacts the alveolar bone for the first time.

Anatomical, numerical, and implant design tridimensional criteria were used to achieve maximal implant primary stability (Table 2). Structural zygomatic stabilization[16] was maximized by the penetration of four cortical areas of the maxillary zygomatic process and zygomatic bone (Fig 2b). To avoid fracture of the zygomatic bone during or after the drilling procedure, a minimum amount of 3 mm of bone thickness was left externally to the implant at the zygoma level (Fig 4g). Accordingly, the final position of the antrostomy was decided in relation to the zygoma buttress curvature. The flatter the zygomatic buttress, the more inferior the initial perforation was located. In the opposite situation, the more pronounced the buttress was, the higher the entrance was performed.

Topographic characteristics of the anatomical structures that were cut by an anterior oblique plane joining the lateral incisor-canine area to the zygomatic bone, representing the planned zygomatic implant path, were studied and classified. Of special interest were the morphology of the nasal floor, alveolar crest, sinus limits, and maxillary wall curvatures. Cross-sectional planes illustrating the virtual planning for anterior and posterior implant trajectories were studied separately. Consequences of anatomy variations on osteotomy positioning at the coronal, medial, and apical levels, including the use of new implant designs, were discussed, and decisions were made by consensus.

The relationship of the zygomatic implant osteotomy with the corresponding anatomical features was grouped, and the percentages corresponding to each osteotomy path for both anterior and posterior implants were calculated.

RESULTS

A total of 122 patients with severely atrophic maxillae met the inclusion criteria for fixed oral rehabilitation anchored on four zygomatic implants. A total of 488 zygomatic implant trajectories were designed; 244 were anterior implants with the starting point of the osteotomy on the anterior incisor-canine area, and 244 were posterior implants with the starting point of the osteotomy on the posterior molar-premolar area. These patients were recruited in different centers, with approximately 25% from Spain and Portugal, 14% from other European countries, 11% from the United States and Canada, 15% from Asia, 15% from Australia and New Zealand, and the remaining 15% from other countries.

The implants placed in the posterior maxilla corresponding to each of the five types of osteotomy paths based on the zygoma anatomy-guided approach[10,11] (ZAGA) were named from ZAGA type P-0 to P-4 (using "P" for posterior). The percentages for each type were as follows: 5.7% for type 0, 10.2% for type 1, 8.2% for type 2, 18.4% for type 3, and 57.4% for type 4. In the same way, implants placed in the anterior maxilla were named from ZAGA type A-0 to A-4 (using "A" for anterior) according to five types of osteotomy paths based on the zygoma anatomy-guided approach.[10,11] Five basic skeletal forms corresponding to implant pathways starting in the anterior maxilla from the lateral incisor/canine zone with the goal of thorough penetration at zygomatic bone could be identified (Figs 5 to 9; Table 3). The corresponding percentages for each type were 2.9% for type 0, 4.5% for type 1, 19.7% for type 2, 55.7% for type 3, and 17.2% for type 4. Notable variations regarding the morphology of the nasal floor, alveolar crest complex, sinus limits, anterior maxillary wall curvatures, and subsequent and depicted anatomical structures of the zygoma anatomy-guided approach for posterior (P) and anterior (A) osteotomy types were found.

In a comparison of the anatomies of the left and right maxilla, symmetric anatomical features were found in 31.1% and 30.7% of the anterior and posterior sites, respectively.

DISCUSSION

The contribution of the present study, in which 122 patients with 488 zygomatic implants were included,

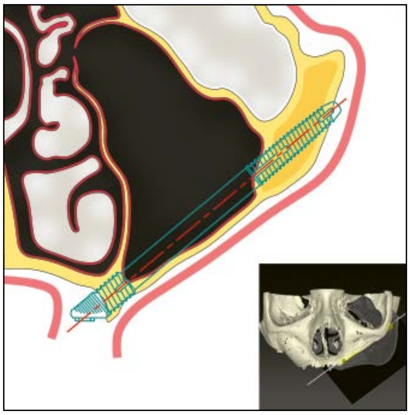
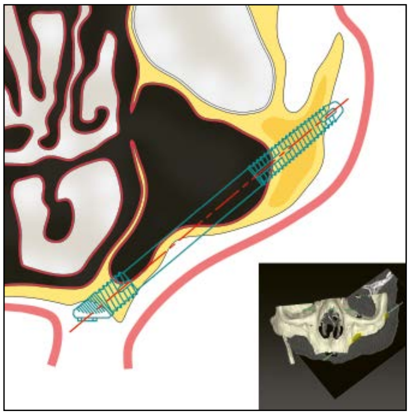
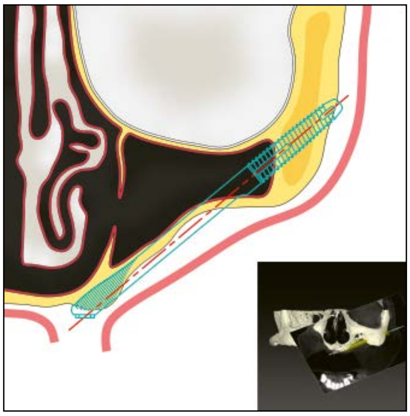




Fig 5 *(Left)* Schematic drawing of a ZAGA type A-0 trajectory model based on the zygoma anatomy-guided approach representing the path of a round designed zygomatic implant with the coronal starting point at the lateral incisor/canine level. The remaining bone architecture has adequate dimensions to embrace the implant neck while it reaches a prosthetically driven anchorage on the zygoma using a totally intrasinus path. On the inferior right side, the 3D image of the corresponding quad model shows the oblique plane that the implant will use to reach the zygomatic bone and the type of maxillary wall curvature.

Fig 6 *(Middle)* Schematic drawing of a ZAGA type A-1 trajectory model based on the zygoma anatomy-guided approach showing the path of a round designed zygomatic implant with the coronal starting point at the lateral incisor/canine level. The remaining alveolar bone architecture and dimensions may embrace the implant neck in almost its total circumference while it reaches a prosthetically driven anchorage on the zygoma using a partial intrasinus path. On the inferior right side, the 3D image of the corresponding quad model shows the oblique plane that the implant will use to reach the zygomatic bone. The maxillary wall is more concave than in the previous type 0 trajectory; part of the implant has an extramaxillary path.

Fig 7 *(Right)* Schematic drawing of a ZAGA type A-2 trajectory model based on the zygoma anatomy-guided approach showing the path of a flat-design zygomatic implant with the coronal starting point at the lateral incisor/canine level. The remaining alveolar bone architecture has no adequate dimensions to embrace the implant neck. The osteotomy is buccally shifted to avoid nose/sinus penetration through a thin bone layer. The implant reaches a prosthetically driven anchorage on the zygoma using a partial extrasinus path. On the inferior right side, the 3D image of the corresponding quad model shows the oblique plane that the implant will use to reach the zygomatic bone. The maxillary wall is more concave than in the previous A-1 situation; most of the implant including the implant neck has an extramaxillary path.

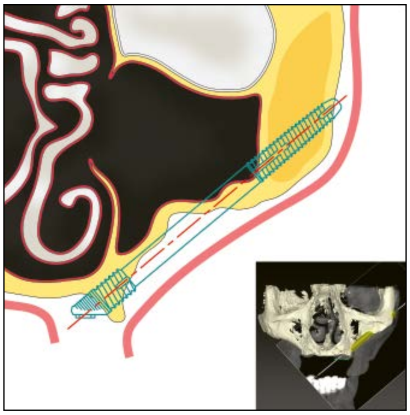
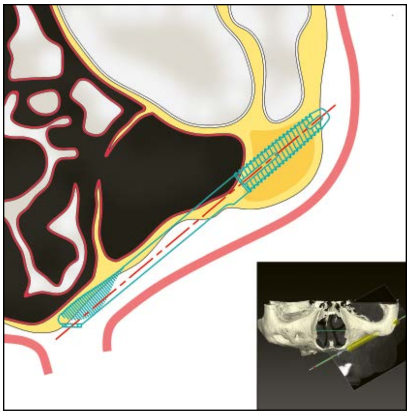



Fig 8 *(Left)* Schematic drawing of a ZAGA type A-3 trajectory model based on the zygoma anatomy-guided approach showing the path of a round designed zygomatic implant with the coronal starting point at the lateral incisor/canine level. The remaining alveolar bone has an architecture adequate in dimensions to total or partially embrace the implant neck. Implant neck circumference is surrounded by alveolar bone. The osteotomy is buccally shifted to avoid nose/sinus penetration through a thin bone layer. The implant reaches a prosthetically driven anchorage on the zygoma using the remaining alveolar bone and a partial extrasinus path. On the inferior right side, the 3D image of the corresponding quad model shows the oblique plane that the implant will use to reach the zygomatic bone. The maxillary wall is very concave. The implant has an initial intra-alveolar path followed by an aerial extramaxillary trajectory before reaching the zygomatic bone.

Fig 9 *(Right)* Schematic drawing of a ZAGA type A-4 trajectory model based on the zygoma anatomy-guided approach showing the path of a flat-designed zygomatic implant with the coronal starting point at the lateral incisor/canine level. The remaining alveolar bone has neither architecture nor the adequate volume to fully embrace the implant neck, which will be partially sunk on bone. The osteotomy is buccally shifted to avoid nose/sinus penetrations through a thin bone layer. The implant reaches a prosthetically driven anchorage on the zygoma using a total extrasinus path. On the inferior right side, the 3D image of the corresponding quad model shows the oblique plane that the implant will use to reach the zygomatic bone. The maxilla is very atrophic. The osteotomy has been shaped in a canal or arc of circumference design. The implant section also has an arc of circumference section.

Table 3 Possibilities and Characteristics of the Osteotomy Trajectory Designed for the Anterior (A) Zygomatic Implant, According to the Zygoma Anatomy-Guided Approach[10,11] (ZAGA), in a Severely Atrophic Maxilla Needing a Rehabilitation Anchored on Four Zygomatic Implants

ZAGA type A-0	The anterior maxillary wall is flat or convex. Providing a minimum 4 mm high × 6 mm wide in an adequate architecture, a circular osteotomy is performed through the remaining alveolar crest. The implant neck is located on the alveolar crest to minimize the risk of late soft tissue complications. A threaded circular implant section is used to seal the tunnel-shaped osteotomy. The antrostomy is placed immediately across the alveolar crest. Sinus lining integrity at the crestal level is not preserved. The implant body reaches the zygomatic bone using an intrasinus path. The implant comes in contact with bone at the alveolar crest and zygomatic bone, and sometimes at the lateral sinus wall.
ZAGA type A-1	The anterior maxillary wall is slightly concave. Providing a minimum 3 to 4 mm high × at least 5 mm wide in an adequate architecture, a circular osteotomy is performed through the remaining alveolar crest. The implant neck is mostly located on the alveolar crest to minimize the risk of late soft tissue complications. A threaded circular implant section is used to seal the tunnel-shaped osteotomy. To properly reach the zygomatic bone, the drill has performed the osteotomy slightly through the anterior maxillary wall. The antrostomy is placed immediately across the alveolar crest. Sinus lining integrity at the crestal level is not preserved. Although the implant can be seen through the wall, most of the implant body has an intrasinus path. The implant comes into contact with bone at the alveolar crest, lateral sinus wall, and zygomatic bone.
ZAGA Type A-2	The anterior maxillary wall is concave. The alveolar architecture is not enough to allocate the implant neck. Final osteotomy has a channel section with floor and lateral walls but no roof. The implant head is partially located on the alveolar crest. An implant section in the shape of a flat arc of the circumference is preferably used to seal the channel type of osteotomy. The drill avoids nasal floor perforation to reach the zygomatic bone. The osteotomy is performed through the anterior maxillary wall, displacing the alveolar initial drilling toward the buccal area. The antrostomy is placed as far as possible from the crest level. Sinus lining integrity at the crestal level is preserved. The implant can be seen through the maxillary wall and most of the body has an extrasinus path. The implant comes into contact with bone at the alveolar crest, lateral sinus wall, and zygomatic bone.
ZAGA type A-3	The anterior maxillary wall is very concave. The alveolar architecture is enough to allocate the implant neck in diameter. Then, a circular osteotomy is performed through the remaining alveolar crest. The implant neck is located on the alveolar crest. The drill will perform a circular osteotomy following a trajectory that goes from the palatal to the buccal alveolar bone; drill "flies" over the most concave part of the anterior sinus wall to penetrate into the zygomatic bone.* A threaded circular implant section is used to seal the tunnel-shaped osteotomy. The antrostomy is placed as far as possible from the crest level. Sinus lining integrity at the crestal level is preserved. Most of the implant body has an anterior extrasinus path. The middle part of the implant body is not touching the most concave part of the wall. The implant comes in contact with bone in the coronal alveolar and apical zygomatic bone.
ZAGA type A-4	The maxilla and the alveolar bone show extreme vertical and horizontal atrophy. The reduction of subnasal bone volume forces the surgeon for an extranasal/extrasinus implant pathway. The alveolar architecture is not enough to allocate the implant neck. Final osteotomy has a channel section with floor and lateral walls but no roof. The implant head is located partially buccally of the alveolar crest. The antrostomy is placed as far as possible from the crest. The osteotomy aims to "sink" the implant as much as possible but respecting sinus lining integrity at the crestal level. The drill has arrived at the apical zygomatic entrance following a path outside the sinus wall. Most of the implant body has an extrasinus/extramaxillary path. Just the apical zygomatic part of the implant is totally surrounded by bone. The implant comes in contact with bone in the zygomatic bone and part of the lateral sinus wall.

*For classification procedures, borderline situations where a pronounced maxillary wall concave curvature is concomitant with a zygomatic implant neck diameter too close to the remaining alveolar thickness, which is not capable of completely covering the implant neck but most of it is buried into alveolar bone, were also classified as type A-3.

is to describe the different osteotomy paths that the anterior implants may follow according to the zygoma anatomy-guided approach[10,11] in a situation where four implants are placed in the extremely atrophied maxilla to withstand a fixed oral rehabilitation. To the authors' knowledge, the anatomy-based trajectories that anterior zygomatic implants may adopt in patients undergoing the quadruple zygoma technique have not been previously reported.

Distinctive features of the concept of the zygoma anatomy-guided approach have been reported in different studies by Aparicio et al.[8,10,11] In a study of 22 consecutive patients treated with the classic zygomatic technique and followed for at least 10 years vs 80 consecutive patients treated according to the zygoma-guided approach and followed for a mean of 4.6 years, the long-term outcomes, such as survival rate, implant stability, sinus conditions, prosthesis design, and soft tissue sealing, were compared.[8] All patients included in the zygoma-guided approach had at least 3 years of prosthetic follow-up, including presurgical and final CT comparisons. Patients in both groups received the same implant design: the original Brånemark Zygomatic Fixture, with a threaded, machined surface design (Nobel Biocare). Both procedures had similar clinical outcomes with respect to implant survival, but the use of the zygoma-guided approach allowed immediate rehabilitation of the severely atrophic maxillae, minimizing the risk of maxillary sinus-associated pathology in comparison with the classic zygoma surgical technique. Moreover, less bulky, more comfortable, and easy-to-clean prostheses were achieved. The accumulated clinical experience of the authors allowed consensus on the referred rationale and protocols helping the clinician on decision-making before performing the osteotomy for anchoring the zygomatic implant. The limitations for the guidelines given in that article[8] were related to the absence of a randomized clinical trial proving the shared data regarding reasons for bone resorption or fistula formation around the zygomatic implant.

When considering zygomatic implant indications, it is important to assess the possibility of taking advantage of residual areas of cortical bone for the apical fixation of regular tilted implants in order to avoid the use of more complex surgical procedures.[17–19] Jensen[20] proposed an anatomical classification for the complete-arch immediate function of oral implants. Although in maxilla class C, the adjunctive use of regenerative procedures is advised, the new classification shows that enough cortical implant fixation can be obtained in the majority of patients to proceed with immediate function. Maxilla class D would provide subnasal bone for placement of two regular implants, and the support for immediate loading is completed with two zygomatic implants. This classification, however, does not include a further maxilla class represented by cases presenting no subnasal bone and requiring four zygomatic implants. Hence, the universally most-accepted clinical indication for the use of the zygomatic anchorage is found when bone is inadequate for regular implant placement not only in the posterior but also in the anterior maxilla. In those situations, the quadruple placement of zygoma implants, with an adequate anteroposterior spread, has proven to be an effective treatment for immediate rehabilitation.[12–15]

The clinical scenario of the severely atrophic maxilla is represented by a thin (≤ 2 mm) bone separating the maxillary nose/sinus from the overlying soft tissue. An eventual implant entry through this minimal bone layer would scarcely achieve enough bone-to-implant contact. Under these conditions, osseointegration able to seal the implant at its neck level would be difficult to achieve and to maintain. The risk for late rhino/sinus-oral communication is then increased. Bone may resorb under function and time in patients with minimal crestal bone around the implant entry point. Becktor et al[21] speculated that the lack of bony support would end up in transversal mobility of the long coronal part of the zygomatic implant facilitating an orosinusal communication, which is in accordance with data reported in the studies by Freedman et al[22,23] showing increased stress forces on the zygoma in situations where alveolar implant support is not achieved.

The minimum amount of residual bone that is able to withstand the different masticatory loads applied from the zygomatic implant to the sinus floor bone-implant junction in the long term remains to be established. Circumstances affecting bone-to-implant contact, quality, and maintenance at the entrance level may present large interindividual differences (ie, difference between final drill diameter and implant diameter, implant insertion precision, quality of zygomatic implant anchorage/stability, quality of soft tissue attachment, oral hygiene, history of periodontitis, etc). In other words, if an intuitively suitable thickness of circumferential alveolar bony support at the zygoma implant neck may be attained (≥ 4 mm height, 6- to 7-mm width), a tunnel type of osteotomy should be the first option regardless of the maxillary curvature. However, due to the lack of evidence and in order to minimize possible implant micromovements, zygoma implants must be splinted to other conventional or zygoma implants in a rigid "cross-arch stabilization system," from the beginning of the treatment, if possible.[24–28]

The term "tunnel osteotomy" has been proposed for a circular osteotomy performed at the coronal osseous entrance with a floor, lateral walls, more or less complete roof, and exiting on the opposite side. According to the zygoma anatomy-guided approach, tunnel osteotomy is recommended whenever it is possible to achieve at least 3 to 4 mm of circular bone-to-implant contact regardless of the maxillary wall curvature. Therefore, a zygoma implant with an appropriate threaded neck profile, surrounded by sufficient bone at the coronal entrance and stabilized by adequate apical anchorage, and prostheses, will achieve osseointegration at the neck level capable of sealing the sinus entrance for the long term. This type of osteotomy is typical of ZAGA types 0, 1, and 3 maxillary wall situations accompanied by an adequate thickness and geometry of alveolar bony support circumferential to the implant neck (Figs 2 and 3). Tunnel osteotomy, by definition, has a circular profile entrance that needs to be sealed by an implant with a round section.

When alveolar bone thickness/architecture is inadequate to achieve at least 3 to 4 mm of circular bone-to-implant contact, implant placement following the zygoma anatomy-guided approach[10,11] is being

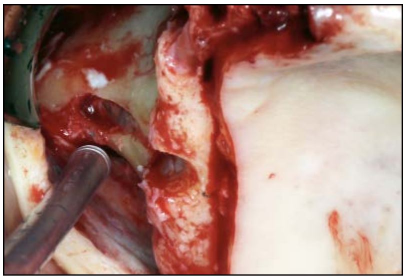


Fig 10a "Channel type" osteotomy at the maxillary right second premolar/first molar position. The remaining alveolar bone that makes up the lateral walls of the canal was preserved. Sinus lining has been unspoiled at the coronal level. Bone-to-implant contact at the coronal level has been improved by laterally shifting the coronal osteotomy.

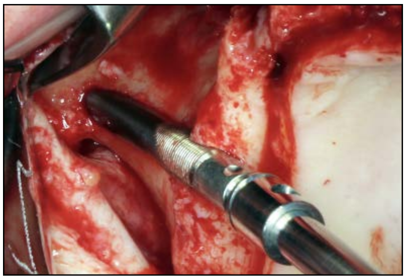


Fig 10b Detail of flat implant design (Straumann ZAGA-Flat, Straumann) during its insertion in an alveolar and maxillary wall "channel type" osteotomy. The implant neck is provided with microthreads just on the bony side to help in the long-term bony maintenance at the coronal level.

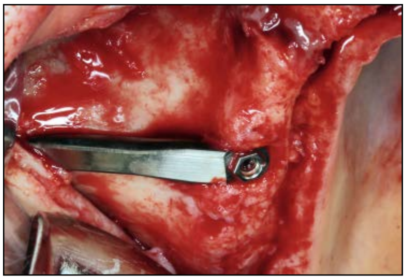


Fig 10c Detail of the flat, nonthreaded, turned titanium surface intended to minimize soft tissue compression/aggression and bacterial adhesion (Straumann ZAGA-Flat, Straumann). Lateral walls of the "channel osteotomy" are of minimal height but still will be useful for soft tissue fibers to attach. The implant head is in a prosthetically driven position and at the same time is sealing the "channel type" osteotomy of Fig 10a (in collaboration with Dr Simon).

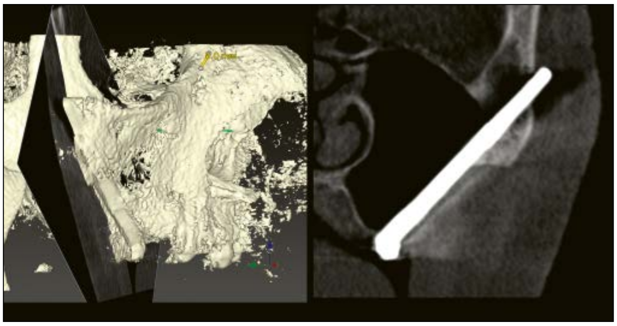


Fig 10d CBCT oblique 2D cut and correspondent plane on 3D vision showing implant position and sinus status of the Fig 10c implant at the 1-year follow-up.

buccally shifted to prevent sinus fistula/infection. The antrostomy position is moved as far as possible from the crest to maintain sinus membrane integrity at this point and to prepare, on the remaining alveolar bone and maxillary wall, a space capable of accommodating most of the circumference of the implant (Fig 4b). This type of osteotomy, not capable of providing a complete covering of the implant mid-body and neck, is known as "channel osteotomy." Its section would be represented by an arc of circumference (Figs 10a to 10c). It is a groove made on the coronal alveolar bone, and sometimes also in the lateral maxillary wall and zygomatic buttress. As a waterway or channel, it has a floor, lateral walls with more or less height, but no roof. The depth limit for the canal digging is membrane integrity at this level.

New soft tissue–related complications have appeared in these situations where the implant is extramaxillary placed, protruding buccally to the maxillary bone crest. Indeed, the presence of the zygoma implant directly beneath the vestibular depth may lead to vascular compression and/or erosion of the mucosa, leading to exposure of the implant. The occurrence of soft tissue dehiscence is difficult to prevent[29] and should be reported.[7,9] To diminish this possibility, a bony canal with a circumferential arc section would, ideally, be sealed by an implant also showing a circumferential arc section (Fig 10). The use of a flat implant section design that fits into a channel would offer an extended flat surface, minimizing its buccal impact against soft tissue vascularization.

Ongoing anatomy studies by Chow´s group (personal communication), are showing an increase in the number of ZAGA type 0 cases for double zygoma as the entry location of the zygomatic implant is moved further backward. The maxillary wall contour is more convex around the zygomatic buttress region, which is usually above the first molar location. Indeed, if the entry site is located at the first molar, more patients presenting with type 0 will appear compared with an entry site at the second premolar. This observation is of total congruence with the results of the present study. The morphology varies according to the cross-sectional plane used. Although there may be remarkable differences in the manifestation of different osteotomy types in the zygoma anatomy-guided approach, the diversity of patients recruited from many parts of the world composes a multiracial and global sample that probably represents the average of what may be observed in different countries.

The possibility for prevention of sinus infection at the time of implant insertion by the use of bone morphogenetic protein-2 (BMP-2) at the subcrestal portion of a newly placed zygomatic implant was suggested by Jensen et al.[6] This could be of benefit whenever there is a risk of pocket development and the sinus cavity is proximate. Data of trans-sinus dental implant placement with BMP-2 grafting to gain anterior-posterior spread for immediate function appears to be a viable alternative to the use of zygomatic implants.[30]

CONCLUSIONS

The trajectory of the zygomatic implant follows different anatomical paths depending on its coronal point being anteriorly or posteriorly located. Topographic characteristics of the anatomical structures that are cut by an anterior oblique plane joining the lateral incisor-canine area to the zygomatic bone, representing the planned osteotomy path in a quad-zygoma indication, were described and grouped in five types. Asymmetric anatomies for the left and right maxilla were found in approximately 70% of the population. The observation of anatomical differences between patients and subsequent adaptation of surgical procedures and implant sections/designs to their anatomy is a crucial factor to reduce potential complications of the quadruple zygoma approach.

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REFERENCES

1. Chrcanovic BR, Albrektsson T, Wennerberg A. Survival and complications of zygomatic implants: An updated systematic review. J Oral Maxillofac Surg 2016;74:1949–1964.
2. Goiato MC, Pellizzer EP, Moreno A, et al. Implants in the zygomatic bone for maxillary prosthetic rehabilitation: A systematic review. Int J Oral Maxillofac Surg 2014;43:748–757.
3. Davó R, Felice P, Pistilli R, et al. Immediately loaded zygomatic implants vs conventional dental implants in augmented atrophic maxillae: 1-year post-loading results from a multicentre randomised controlled trial. Eur J Oral Implantol 2018;11:145–161.
4. Felice P, Barausse C, Davó R, et al. Immediately loaded zygomatic implants versus conventional dental implants in augmented atrophic maxillae: Three-year post-loading results from a multicentre randomised controlled trial. Clin Trials Dent 2020;02:5–25.
5. Brånemark PI, Gröndahl K, Ohrnell LO, et al. Zygoma fixture in the management of advanced atrophy of the maxilla: Technique and long-term results. Scand J Plast Reconstr Surg Hand Surg 2004;38:70–85.
6. Jensen OT, Adams M, Cottam JR, Ringeman J. Occult peri-implant oroantral fistulae: Posterior maxillary peri-implantitis/sinusitis of zygomatic or dental implant origin. Treatment and prevention with bone morphogenetic protein-2/absorbable collagen sponge sinus grafting. Int J Oral Maxillofac Implants 2013;28:e512–e520.
7. Aparicio C, López-Piriz R, Albrektsson T. ORIS criteria of success for the zygoma-related rehabilitation: The (revisited) zygoma success code. Int J Oral Maxillofac Implants 2020;35:366–378.
8. Aparicio C, Manresa C, Francisco K, et al. Zygomatic implants placed using the zygomatic anatomy-guided approach versus the classical technique: A proposed system to report rhinosinusitis diagnosis. Clin Implant Dent Relat Res 2014;16:627–642.
9. Aparicio C, Manresa C, Francisco K, et al. Zygomatic implants: Indications, techniques and outcomes, and the zygomatic success code. Periodontol 2000 2014;66:41–58.
10. Aparicio C. A proposed classification for zygomatic implant patient based on the zygoma anatomy-guided approach (ZAGA): A cross-sectional survey. Eur J Oral Implantol 2011;4:269–275.
11. Aparicio C (ed). Zygomatic Implants: The Anatomy-Guided Approach, ed 1. Chicago: Quintessence, 2012.
12. Duarte LR, Filho HN, Francischone CE, Peredo LG, Brånemark PI. The establishment of a protocol for the total rehabilitation of atrophic maxillae employing four zygomatic fixtures in an immediate loading system—A 30-month clinical and radiographic follow-up. Clin Implant Dent Relat Res 2007;9:186–196.
13. Stiévenart M, Malevez C. Rehabilitation of totally atrophied maxilla by means of four zygomatic implants and fixed prosthesis: A 6–40-month follow-up. Int J Oral Maxillofac Surg 2010;39:358–363.
14. Davo R, Pons O, Rojas J, Carpio E. Immediate function of four zygomatic implants: A 1-year report of a prospective study. Eur J Oral Implantol 2010;3:323–334.
15. Davó R, Pons O. 5-year outcome of cross-arch prostheses supported by four immediately loaded zygomatic implants: A prospective case series. Eur J Oral Implantol 2015;8:169–174.
16. Nkenke E, Hahn M, Lell M, et al. Anatomic site evaluation of the zygomatic bone for dental implant placement. Clin Oral Implants Res 2003;14:72–79.
17. Mattsson T, Köndell PA, Gynther GW, Fredholm U, Bolin A. Implant treatment without bone grafting in severely resorbed edentulous maxillae. J Oral Maxillofac Surg 1999;57:281–287.
18. Krekmanov L, Kahn M, Rangert B, Lindström H. Tilting of posterior mandibular and maxillary implants for improved prosthesis support. Int J Oral Maxillofac Implants 2000;15:405–414.
19. Aparicio C, Perales P, Rangert B. Tilted implants as an alternative to maxillary sinus grafting: A clinical, radiologic, and Periotest study. Clin Implant Dent Relat Res 2001;3:39–49.
20 Jensen OT. Complete arch site classification for all-on-4 immediate function. J Prosthet Dent 2014;112:741–51.e2.
21. Becktor JP, Isaksson S, Abrahamsson P, Sennerby L. Evaluation of 31 zygomatic implants and 74 regular dental implants used in 16 patients for prosthetic reconstruction of the atrophic maxilla with cross-arch fixed bridges. Clin Implant Dent Relat Res 2005;7:159–165.
22. Freedman M, Ring M, Stassen LF. Effect of alveolar bone support on zygomatic implants in an extra-sinus position—A finite element analysis study. Int J Oral Maxillofac Surg 2015;44:785–790.
23. Freedman M, Ring M, Stassen LF. Effect of alveolar bone support on zygomatic implants: A finite element analysis study. Int J Oral Maxillofac Surg 2013;42:671–676.
24. Davo R, Malevez C, Rojas J. Immediate function in the atrophic maxilla using zygoma implants: A preliminary study. J Prosthet Dent 2007;97(6 suppl):s44–s51.
25. Davó R. Zygomatic implants placed with a two-stage procedure: A 5-year retrospective study. Eur J Oral Implantol 2009;2:115–124.
26. Brunski J. Biomechanical aspects of tilted regular and zygomatic implants. In Aparicio C (ed). The Anatomy-Guided Approach. Berlin: Quintessence, 2012:25–45.
27. Skalak R. Biomechanical considerations in osseointegrated prostheses. J Prosthet Dent 1983;49:843–848.
28. Xu X, Zhao S, Liu H, Sun Z, Wang J, Zhang W. An anatomical study of maxillary-zygomatic complex using three-dimensional computerized tomography-based zygomatic implantation. Biomed Res Int 2017;2017:8027307.
29. Aparicio C, Sanz A. Zygoma anatomy-guided approach "scarf graft" for prevention of soft tissue dehiscence around zygomatic implants: Technical note. Int J Oral Maxillofac Implants 2020;35:e21–e26.
30. Jensen OT, Cottam J, Ringeman J, Adams M. Trans-sinus dental implants, bone morphogenetic protein 2, and immediate function for all-on-4 treatment of severe maxillary atrophy. J Oral Maxillofac Surg 2012;70:141–148.