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Review Article

Dentistry Section

Surgical Procedures for Placement of Zygomatic Implant- A Review

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ABSTRACT

Zygomatic Implants (ZIs) have become a popular choice in recent times, which anchor the dense Zygomatic Bone (ZB). Unlike maxillary bone, ZB does not resorb and acts as a ladder step that takes most of load similar to the pillars of a ladder, thereby providing an obvious advantage for implant placement. These ZIs are an alternative to conventional implants in narrow/atrophic maxillary ridges, that require grafting techniques which might be quite expensive, time-consuming. Whereas, on the other hand ZIs are relatively quick, painless, and with an immediate implant loading prosthesis protocol. The objective of this review article was to study the published literature for various surgical techniques available for the placement of ZI and the procedures through which they are done. An extensive search of electronic databases like PubMed, Google Scholar, CrossRef, Science Direct was performed. Key search terms used were dental implant, zygomatic arch, atrophy, maxillary sinus, surgical techniques, quad zygoma, defective maxillary bone. The clinician's experience, proper clinical assessment, case selection and use of appropriate surgical procedure are imperative for the success of ZI. Among various available surgical techniques, a single technique is preferred over the other based on anatomy of the maxillary sinus, skeletal forms of zygomatic buttress-alveolar crest complex and prosthetic bailout.

Keywords: Immediate dental implant loading, Osteotomy, Zygoma

INTRODUCTION

The ZIs are a milestone of progress in the genesis of oral implantology [1]. Although several substitute treatment options are available as an alternative to ZI such as Lefort osteotomies [2], synthetic biomaterials, implants in pterygoid apophysis, angled implants in the parasinus region [3,4] and wide and short implants [5] to address the maxillary bone deficiency, they are expensive with chances of second surgical site morbidity.

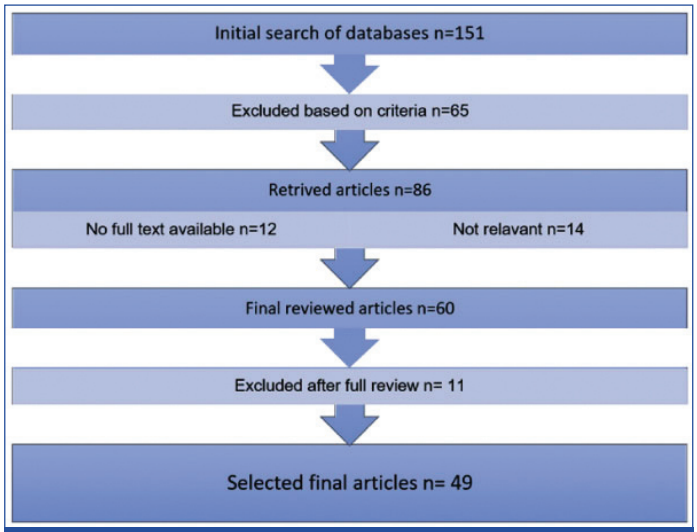
Furthermore, patients are not allowed to wear even partial dental prosthesis during this healing period. Admittedly, P-I Brånemark's concern for patients suffering from atrophic jaws, in 1980s, introduced using ZI for anchorage in hemi-maxillectomy cases [6,7] and converted this conception to edentulous patients with an atrophic maxillary ridge. ZI, in combination with endosteal implants placed in the anterior maxilla able to deliver masticatory forces through screw retained temporary prosthesis and providing splinting effect to the rest of all implants [8].

Surgical placement of the ZI is difficult due to the complex anatomy of the zygomatic bone and limited surgical site view [9]. Moreover, the length of ZI is almost five times longer in length, so that a minor error in the entry point may result in a serious deviation at the exit point. Also, as the paths of ZIs are adjacent to the orbit and infra-temporal fossa, the suborbital nerve and vascular bundle, a tiny operative error may lead to serious surgical complications, such as the paths of ZIs are adjacent to the orbit and infra-temporal fossa, the suborbital nerve and vascular bundle [10]. In the majority of the patients suffering from severe atrophy of the maxilla will have a single chance to replace his/her missing teeth with a fixed prosthesis anchored by ZIs. Therefore, the treatment must be performed by a trained expert, as it must be successful on the first attempt [11].

The aim of this review was critical evaluation of material published in literature, till date for ZI placement, success rate associated with each technique and to review their potential shortcomings, which thereby provide readers with a state-of-the-art understanding regarding various techniques available for ZI placement and procedure through which they are done.

LITERATURE SEARCH

An extensive search of electronic databases such as (PubMed, Google Scholar, CrossRef, Science Direct) was performed. Search terms used were dental implant, zygomatic arch, atrophy, maxillary sinus, surgical techniques, quad zygoma, defective maxillary bone. The works of literature were searched based on the pre-determined inclusion and exclusion criteria [Table/Fig-1].



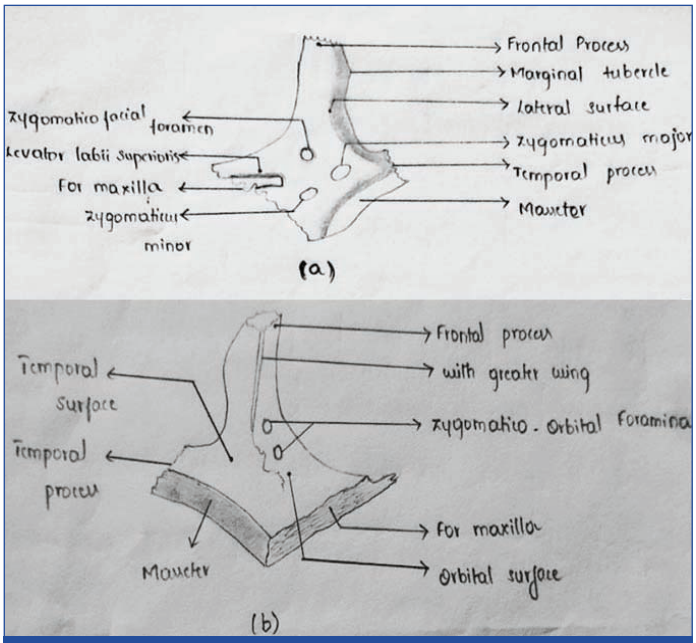
[Table/Fig-1]: Flow diagram of the included studies.

Inclusion criteria: Articles which were related to ZI focusing mainly on surgical techniques available in literature, accessible online with full text and those studies with combined case series report and review articles which are reliable and concerned to the study were included. This review study included the articles which were published between the years 1976 to 2020.

Exclusion criteria: The research studies in which only abstract were available were excluded. Investigations which were duplicate and with questionable results, simple case reports and letters to editor were also excluded from the study.

ANATOMICAL CONSIDERATIONS FOR ZI PLACMENT

Anatomical knowledge of the ZB is an important consideration during a ZI placement regarding its volume, quality, and quantity. In general, the ZB presents with trabecular pattern for osseointegration and thick cortical bone useful for primary stabilisation [8]. The zygomaticofacial nerve emerges from the Zygomaticofacial Foramen (ZFF) which supplies nerve innervation to the cheek in zygomatic region. Anatomical understanding of ZFF is important for surgeons when planning surgery in this region. It is considered that the central portion of the ZB is the safest place to anchor ZI since ZFF is less widely located [12]. It is mostly preffered that orbital cavity's lateral margin and infraorbital margin, both can be used to anchor the ZI, according to Rigolizzo MB et al., [13]. [Table/Fig-2] illustrates the anatomical landmarks of left ZB both on the outer and inner view [14].



[Table/Fig-2]: Free hand sketch representing the features of left ZB: a) outer view; b) inner view [14].

BIOMECHANICS OF ZI

The prognosis of a dental implant depends on how stresses are distributed from the implants to the surrounding bone. Stress distribution within both bone and implant can be determined by finite element analysis [15]. Finite Element Analysis (FEA) was first used by Weinstein AM et al., in 1976 [16]. Improved bone quality such as greater density bone effects, the biomechanical properties in the implant bone interface in a positive way leading to implant success. It was noted that stress apportion, when compared with the amount of maxillary atropy, type-IV Zygoma Anatomy Guided Approach (ZAGA) with increased vertical and horizontal atrophy led to greater stress distribution due to lack of adequate alveolar bone support and depleted cortical anchorage when compared with ZAGA type-I [17].

The volume of the surrounding bone depends on the quality and quantity of the bone, interface between implant and bone, the diameter and length of the implants, the shape of the implant surface, and the prosthesis type. FEA allows researchers to predict stress distribution in the contact area of the implants with cortical bone and around the apex of the implants in trabecular bone [15]. A previous study showed that, in ZIs stress gets divided between the temporal and frontal process of the ZB by transferring through the infra-zygomatic crest instead of concentrating stress around the alveolar bone [18].

TECHNIQUES

Success outcomes with respect to various surgical techniques along with their key features and indications are described in [Table/Fig-3] [19-26].

The Classical Approach

In the year 1998, Branemark P was the first one to introduce this technique [27].

Operative technique: After administering bilateral infraorbital nerve block and greater palatine block, the approach begins with a palatal incision between the first molar regions bilaterally. Then the palatal flap is reflected, this exposes the palatal margin of the alveolar ridge and hard palate. Buccal flap and the nasal mucosa is reflected

Technique	Author's name*	Year	Zygomatic Implants (ZI)	FAILED ZIs	Success outcomes§	Key features†	Indications‡
Classical	Hirsch JM et al., [19]	2004	124	3	97.9%	No special effort was made to keep the sinus mucosa intact.	When maxilla is severely resorbed, and concavity formed is small.
Sinus slot	Penarrocha M et al., [20]	2007	40	0	100%	Without the concern of compromise to the sinus membrane, the slot is made through the buttress wall.	If implants should emerge close to the top of the crest, to prevent bulky prosthesis and with more vertical angulation.
Exteriorised approach	Coppede A et al., [21]	2017	94	1	98.9%	No maxillary antrostomy is necessary.	In situations where the maxillary sinus lateral aspect shows pronounced buccal concavity.
Custom made drill guides	Van Steenberghe D et al., [22]	2003	6	1	linear deviations <3 mm, angular deviations <5 degree	Based on the patient's bone profile individualised drill guide is created.	Increased surgical complexity and variable zygoma anatomy encourages the use of a validated 3D CT planning system to achieve optimal transfer of the planning to the surgical field.
CAS Navigation system	Wang F et al., [23]	2018	15	0	100%	Use of a software system for implant placement. Intraoperative changes, if necessary, can be implemented.	When intended to decrease overall operative time and errors.
Zygoma Anatomy Guided Approach (ZAGA)	Davo R et al., [24]	2020	182	0	100%	Standardised procedure and attains stability of soft tissue with critical intent of correct sinus sealing.	Procedure can be applied to different maxillary anatomies. Where implant placement can be classified into five types, depending on the anatomy of the maxillary wall and the path of the implant.
Quad zygoma	Duarte LR et al., [25]	2007	48	1	97.9% [25]	Quad zygoma technique increases the possibility of anchorage of the implant since its apex is positioned in the ZB, with dissemination of lateral and axial loads.	In cases where it is impossible to place conventional implants in the premaxillary region due to resorbed canine pillars, the quad zygoma technique is preferred.
	Stiévenart M and Malevez C [26]	2010	80	3	96% [26]		

[Table/Fig-3]: Zygomatic Implants (ZI) - Success outcomes with respect to the surgical technique along with their key features and indications [19-26].
*The articles which discussed only the technique are not included: [27] for classical technique, [28] for sinus slot technique, [29] for exteriorised approach, [30] for computer-aided surgical navigation system and [31] for ZAGA approach; Information obtained from them is mentioned in under respective surgical techniques; †‡key features and indications are generalised to the surgical technique not specific to a particular study; §success outcomes selected in this review are obtained from the follow-ups conducted on patients who underwent the specific surgical procedure. Studies which conducted follow-up on a combination of various techniques were not included; CAS: Computer-aided surgical

to view nasal crest, from here the flap is raised till infra zygomatic crest, locate the infraorbital nerve and reflect till the zygomatic bone area is exposed [28,29]. A fenestra is then created in the lateral uppermost aspect of the sinus wall, by using a round bur and sinus mucosa is reflected. The window perforates through the sinus providing clear view of the roof of the sinus enabling localisation of the optimal point for the drill into the ZB entrance. From a prosthetic perspective, the favourable entrance is as far posterior and adjacent to the crestal midline.

With the use of a round bur (Ø 2.9 mm), the drilling starts from the palatal side of the ridge and is used to penetrate the crest and sees the entrance in the roof of the sinus. The entire site in the zygomatic bone is prepared with a twist drill of (Ø 2.9 mm), sequential drill of 3.5 mm is used. The correct length of the ZI is decided by using a depth probe. This length corresponds from the alveolar ridge to the ZB osteotomy site. A 4 mm countersink drill may be used if the palatal bone is impenetrable. To position in an optimal way from the prosthetic perspective, it is steadily incorporated until its apical portion is anchored in the alveolar crest, and the implant is manually inserted to its adequate depth [30]. To refrain the formation of a retrozygoma space, the muscles that were released from the lower anterior aspect of the zygoma should be carefully repositioned. Individual absorbable sutures were used [31]. In this procedure, to permit placement of two to four anterior maxillary implants combined with the ZIs sufficient alveolar bone must be present in the anterior maxilla and also involves rigid splinting of the implants [27,32,33].

Limitation(s): Intra-sinus path leads to an undesirable palatal emergence of the implant head in patients with pronounced buccal concavity on the lateral aspect of the maxillary sinus. Due to which the final prosthesis is bulky and difficult to maintain [34].

Sinus Slot Technique

Stella JP and Warner MR (2000) invented the sinus slot technique [28]. The procedure begins with an incision on the crestal surface joining both tuberosities. A bilateral vertical releasing incision with elevation to accomplish Lefort-1 exposure extends upto the inferior aspect of the zygoma bilaterally, palatal mucosa reflected. With the help of the fissure bur, a hole is made through the bone into the sinus cavity at the superior region of the contour of the zygomatic buttress, a hole is made into the sinus cavity through the bone with a fissure bur. To simulate the implant twist drills, a depth gauge is positioned in the bur hole, 5 mm above to the ridge's crest and the next drill hole is made after that. Connecting the two bur holes, a sinus slot is then made. The upper point continued to reach the base of the zygoma region, on contrary the inferior slot approaches the floor of the maxillary sinus. With a round bur at the ideal location on the crest of the ridge, lining up with the sinus slot a small purchase point is marked. In the purchase point, The tip of the zygomatic twist drill (Ø 2.9 mm) is placed, and the drill is directed directly through the sinus slot and the tip of the drill is guided through the centre of the slot under direct visualisation. To the junction of the lateral orbital rim and zygomatic arch, the drill is extended superiorly. Through the centre of the sinus slot, the pilot drill and twist drill of 3.5 mm is then used subsequently.The appropriate length of the implant was chosen based on the depth of penetration. Cutting threads on either side of the sinus slot are visible during the implant placement [28,34].

Advantages: This technique bypasses the need for a lateral window and decreases the chance of sinus perforation, which also allows the implant head to emerge at the height of the alveolar crest instead of palatal emergence [35].

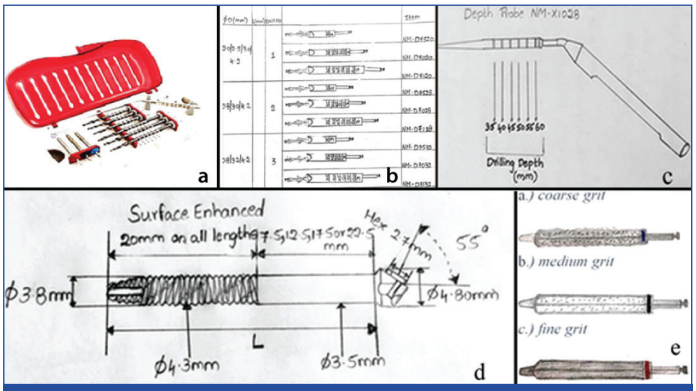
Limitation(s): Achieving accurate match of the implant drilling as a separate procedure, it prevents a precise matching of the implant surface to the sinus slot bone preparation. Moreover, in cases where the anatomy of the sinus wall is very concave, there is no need to prepare a slot [11].

The Exteriorised Approach

Miglioranca R et al., introduced the Exteriorised technique in the year 2006 [29]. In this technique supracrestal incision is given from one tuberosity extending upto the contralateral tuberosity, combining with two vertical releasing incisions in the region concerning to zygomatic pillars. Mucoperiosteal flap is elevated. The ZIs are placed external to the sinus cavity, which thereby contacts the lateral wall's outer aspect of the maxillary sinus, by placing as distally as possible depending on the anatomy of the patient's profile, most ideally in the first molar or second premolar region. No maxillary antrostomy is required. The osteotomy for the implant placement starts with the use of a spherical drill, penetrating near the top of the crest of the residual ridge, from palatal to buccal aspect, emerging at the buccal aspect of the ridge, external to the sinus in the buccal aspect of the ridge. Drilling proceeds until it reaches the ZB, ongoing through the outer surface of the lateral wall of the maxillary sinus. Further with the usage of the same spherical drill, the ZB is perforated until it surpasses the outer cancellous layer of the bone. Then to determine the ZI length, the depth indicator is used which is bounded as 2 mm less than the acquired measurement. Later on, the osteotomy is widened progressively by utilising the following drills in sequential order: twist drill, 2.9 mm; pilot drill, 2.9/3.5 mm; and twist drill, 3.5 mm. Insertion torque of 40 N cm, is used to place the implants initially, later which the insertion is completed manually. The platform of ZIs becomes visible over or next to the top of the residual alveolar ridge's crest [29,36,37].

Advantages: Implant takes an extra maxillary path avoiding perforation of the Schneiderian membrane. This protocol enables better and direct visualisation of the zygomatic osteotomy and aids in positioning the implant's head, less palatally than the classical surgical protocol would achieve in all anatomic circumstances [38,39].

[Table/Fig-4] depicts the instruments designed for simplicity of use during Zygomatic Implant placement.



[Table/Fig-4]: Pictures drawn depicts the instruments which are designed for simplicity of use during ZI placement by NORIS MEDICAL Dental Implant Solutions, standing for: a) ZI surgical kit; b) Zygomatic step drills; c) Depth probe; c) ZI Design; e) Zygomatic burs for groove preparation.

Zygoma Anatomy Guided Approach (ZAGA) Surgical Procedure

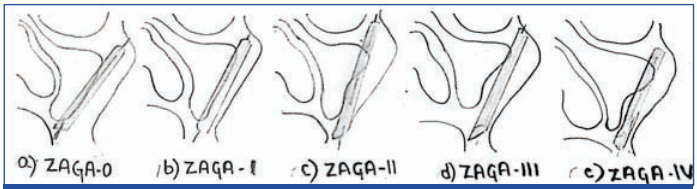
In 2011, Aparicio C proposed the ZAGA approach which is a modification of the exteriorised technique, and which can be applied to different maxillary anatomies. The entry point is crestal, the apical anchorage is in the ZB, and the implant path depends on the degree of maxillary resorption [31,40-43].

A slightly bevelled palatal incision from maxillary tuberosity to the midline is to be given. A relieving incision is made till the nasal floor is seen. The mucoperiosteal flap is reflected to expose the crest, infraorbital nerve, and of the maxilla upto the superior rim of the ZB. To achieve mid-crystal implant head emergence, a mesio-distal entrance at the level of the second premolar/first molar regions is preferred, when two ZI are to be placed. Whereas, when four ZI are used, the anterior implant position should be approximately between the canine and the lateral teeth. Osteotomy is performed from palatal side of the

Type	Anterior maxillary wall	Implant head	Osteotomy	Window osteotomy	Implant position	Implant body-path
ZAGA-0	Very flat	Located on pristine bone provided it has a minimum of 4 mm height and 6 mm width.	A precise under prepared osteotomy has performed through the crestal bone height and sinus floor lining.	Intact sinus lining must be considered.	Implant contacts bone at the alveolar crest and ZB and at times at the lateral sinus wall.	The implant body has an intra-sinus path.
ZAGA-I	Slightly concave	On the alveolar crest, provided a minimum of approximately 4 mm bone height.	Performed the osteotomy slightly through the wall.	No need for a prior window osteotomy because the remaining alveolar crest is slightly tilted buccally, allowing for an exteriorised technique.	Contacts bone at the alveolar crest, lateral sinus wall, and ZB.	Combined intra-extra path.
ZAGA-II	Concave	On the alveolar crest.	Same as in ZAGA-I where osteotomy performed corresponding with the shape of the implant.	No sinus window is performed.	Same as in ZAGA-I	Combined extra–intra path.
ZAGA-III	Very concave	On the alveolar crest.	Osteotomy of alveolar bone goes from palatal to the upper buccal side.	Neither slot or window is performed priorly. The middle part of the implant body is not contacting the most concave part of the wall.	Contacts bone in the coronal alveolar and apical ZB.	In (alveolar)-out (extra-sinus)-in the (zygomatic) path.
ZAGA-IV	Atrophic maxillary bone	Buccal to the alveolar crest.	There is no or minimal osteotomy at this level. Drill has arrived at the apical zygomatic entrance following a path outside the sinus wall.	Bone is surrounded to implant.	The bone at the zygoma and lateral sinus wall.	Extra-maxillary path

[Table/Fig-5]: Zygomatic Implants (ZI)- Success outcomes with respect to the surgical technique along with their key features and indications [19-26].
ZAGA: Zygoma anatomy guided approach; ZB: Zygomatic bone

crest when enough bone is found, if not, osteotomy is performed on the buccal side of the remaining ridge. Final contour of coronal entrance point is determined by the degree of bone resorption and by the anatomy at crestal level. The goal for ZI induction is to accomplish an implant bed matching the implant configuration. Neither a window nor a slot is perforated during the procedure. Alternatively, direct zygomatic osteotomy, coincident with the implant path, is performed [11]. [Table/Fig-5] shows the ZAGA protocol and implant placement classified into five types [11,36] whereas [Table/Fig-6] shows a diagrammatic illustration of the same [31].



[Table/Fig-6]: Diagrammatical illustration which is a free hand portrayal representing the five possible trajectories of the ZI according to the ZAGA Classification for the maxillary wall. From Apacario C [31].

Quad Zygoma

Quad Zygoma technique was introduced by Duarte LR et al., and Stiévenart M and Malevez C [25,26].

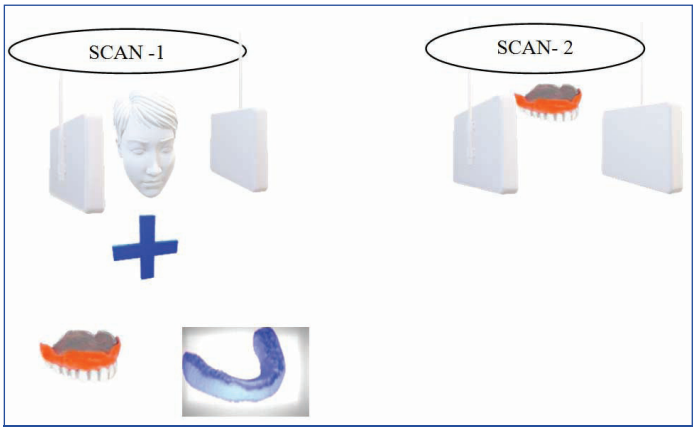
In cases of severe atrophy within premaxillary region creating a difficulty to place standard implants a protocol was introduced to place four ZI widely known as the quad zygoma. Its use was taken up quickly with the four implants being immediately loaded. Surgical technique was described by Stievenart M and Malevez C [26]. A full thickness palatal-crestal incision is made from the first molar to the first molar. Two oblique distal releases are made on each side. Additionally, part of the palate is dissected to facilitate access and visibility [25]. The procedure continues by creating an oblique lateral window of 5×1.5–2 cm in the external wall of the maxillary sinus in order to detach the sinus membrane and to provide visual or tactile access to the internal cortex of the ZB. Once the Schneiderian membrane has been carefully moved, the field is ready for implant insertion [44].

Anterior implants are placed first, with emergence at the level of canines or lateral incisors, followed by posterior implants with emergence in the molar or premolar areas. Implants are evenly positioned allowing a safe distance between them in the ZB. Drilling begins with a 2.9 mm round drill and continues with 2.9- and 3.5-mm diameter cylindrical cutters. To avoid overheating, drilling must be carried out with irrigation. After ZI insertion standard abutments are placed, dissected soft tissue is sutured ensuring adequate union of margins. The procedure continues with prosthesis connection [45].

Guided Implant Surgery (CAS Navigation System)

The aim is to create an individualised drill guide that is suited to the patient's bone profile. A Computer-Aided Design (CAD)/Computer-Aided Manufacturing (CAM) program uses the shape of the bone and the three Dimentional (3D) information of the planned drill paths to design the drill guide. The drill guide is then produced by stereolithography [17,22].

- **In total edentulous cases:** The dual Computed Tomography (CT) scan protocol, requires two Cone Beam Computed Tomography (CBCT) scans: the first scan is the patient wearing the radiographic template, and the second scan is the radiographic template alone as shown in [Table/Fig-7]. Then both Digital Imaging and Communications in Medicine (DICOM) data sets are merged together in the implant planning software, implant is planned based on the CBCT, while the surgical guide is designed and generated based on the radiographic template. The surgical template in this case scenario is a mucosa-supported guide [46].
- **In Edentulous cases:** Who require modification of the alveolar ridge: When coronal part of the ridge is too thin for implant placement, a bone reduction should be done. The dual Computed Tomography (CT) scan protocol is used in these cases for planning implant position. A bone reduction guide



[Table/Fig-7]: Image created with the use of smart art 3D shapes demonstrating the dual scan protocol [46].

is designed using the planning software. The implant surgical guide is generated on the virtual model of the reduced maxilla. The surgical guides, in this case, are bone-supported [46].

- **In partially edentulous cases:** Instead of the full clearance of the dentition, trying to keep the remaining teeth to support the surgical guide (a tooth-supported guide) and placing some of the implants, followed by dental clearance and placement of the remaining implants using a second surgical guide is found to provide better accuracy because the surgical guides are supported by rigid structures throughout the surgery which is reffered as- 'staged guides approach' [46].

According to Raico Gallardo YN et al., and Ozan O et al., tooth-supported and mucosa-supported guides provide better accuracy when compared to bone-supported guides [47,48].

Computer-Aided Surgical (CAS) Navigational System

For less invasive and correct placement, the use of a CAS navigational system has been proposed in ZI, which transfers the preoperative information to the current operative surgical site [49]. Moreover, although several CAS navigation system software have been presented such as (VectorVision2®, BrainLAB) their applications have been rarely reported in ZI surgery [23].

Preoperatively data is transferred into a multiplanar view for accurate inspection of anatomic sites. To achieve measurement of volume, distance, and angle of any marked site. Virtual planning of the implant is carried [30,32]. To the patient's maxilla, an LED emitter array is attached directly. Surgical tools are positioned relative to the position of this array which can be used to compute a mathematical transformation that conveys the coordinate system of the CT scan to the patient. Constant visualisation of the drill trajectory on the computer screen can be seen, while deviation from the preoperative plan position is detected and displayed in real-time [30,32,50,51].

Why should clinicians consider static or dynamic navigation?

Freehand methods result in more errors significantly when compared with navigation methods [52]. The question for the clinician is whether to implement a dynamic or static navigation system. The choice of which depends on the clinician's preference and experience. Dynamic navigation is flexible, convenient, time-saving which thereby permits the clinician to modify the surgical plan as the clinical situation dictates. As it has no laboratory work requisition, which thereby allows for quick scanning, planning, and guidance on the same day as patient presentation. Whereas on the other hand, a static navigational system has a predetermined implant position, no intraoperative position changes can be made. However, the selection will still depend on case-specific considerations [53].

SURGICAL COMPLICATIONS IN ZI

Most-reported complications associated with ZI are postsurgical sinusitis [54], non osseo integrated implants, local infection, fistula at implant level, paraesthesia [55], including periorbital and conjunctival haematoma, oedema, and epistaxis [56]. Some of the more serious complications could even include orbital floor perforation, and perforation into the infratemporal fossa [57]. Although ZI surgery is safe and predictable, it can also result in many possible complications, therefore, it should be reserved only to expert with vast surgical experience, as it requires a long learning curve and prior experience with conventional implants [55].

CONCLUSION(S)

Zygomatic Implants (ZIs) were commonly used for rehabilitation of patients with atrophic upper jaw. Based on available literature, out of various surgical procedures, classical technique is used when maxilla is severely resorbed and when its concavity is small. Whereas, in case maxillary resorption creates a large concavity exteriorised placement of ZI is preferred. Guided implant surgery is advantageous in some cases where an individualised drill guide that is suited to the patient's profile can be created using CAD/CAM program but awareness at each step for possible errors in deviation is required, which would not pose a problem if CAS were utilised. As CAS navigation system provides constant visualisation of the drill trajectory on the computer screen where deviation from the preoperative plan position is detected and displayed in real time. ZAGA is a preferred technique as it standardises the procedure guides the clinician towards an ideal prosthetic implant position for anchorage, while also helps in attaining critical long-term goals of correct sinus sealing and soft tissue stability. Nevertheless of their fringe benefits, ZIs still need studies focusing on their shortcomings like bone resorption leading to loss of fixation, osseointegration failures and postoperative sensorial alterations. Furthermore, additional clinical evidence is required on their aesthetic outcomes, and physiological characteristics.

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