Maxillary All-on-Four® Surgery: A Review of Intraoperative Surgical Principles and Implant Placement Strategies

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BACKGROUND

Implant rehabilitation of full-arch maxillary edentulism has undergone significant changes since the concept of osseointegration was first introduced. Controversy over the ideal number of implants, axial versus angled implant placement, and grafting versus graftless treatment modalities have been subjects of continuous debate and evolution. Implant supported full-arch rehabilitation of the maxilla was originally thought to be more difficult than its mandibular counterpart due to lower overall bone density.

The foundation for any implant supported full-arch rehabilitation is the underlying bone. The dilemma faced by most surgeons is whether to treat this residual bone in an additive fashion through bone augmentation, or a graftless fashion utilizing angled implants secured in residual bone. Advocates for additive treatment attempt to procure the bone volume necessary for implant support through horizontal and vertical augmentation techniques. Graftless approaches seek to offer full-arch implant support through creative utilization of angled implants in existing native bone.

Biomechanical analysis of the masticatory system repeatedly demonstrated that the greatest bite forces are located in the posterior jaws. Anatomic limitations of bone availability due to atrophy and sinus pneumatization make maxillary posterior implant placement challenging. The resulting controversy with regards to full-arch rehabilitation was whether prostheses with long distal cantilevers could be tolerated. If tilting posterior implants could circumvent anatomic limitations while maximizing the use of residual bone, cantilevers could be reduced.

Nonaxial placement and loading of implants was thought to be biomechanically unfavorable preventing osseointegration and leading to increased peri-implant bone loss.[1] Limitations imposed by residual maxillary bone availability and the requirement for axial placement of implants meant cantilever length often needed to be 20 mm or greater in order to provide molar occlusion. Conversely, literature at the time reported a direct association between cantilever length and marginal bone loss/failure of underlying implants.[2] It had been shown that prostheses with cantilevers less than 15 mm survived better than those with cantilevers greater than 15 mm.[3]

Today, Maxillary All-on-Four® is a common treatment modality utilized by clinicians all over the world for immediate full-arch rehabilitation. The technique evolved as a graftless solution which sought to reduce treatment time and avoid complications associated with bone grafting. Potential bone grafting complications include: increased cost, increase treatment time, donor site morbidity, significant limitations imposed by chronic systemic medical conditions, and unpredictable reduction in bone graft volume as a result of resorption.

Tilted implants were proposed as a method to avoid anatomic structures while achieving sufficient biomechanical support. By tilting implants, dense cortical bone of the natural maxillofacial buttresses could be engaged, even in cases of severe maxillary atrophy. Theoretical advantages of tilting implants included:

1. Avoidance of anatomic structures.
2. Longer, tilted implants could be placed in cases of vertical bone deficiency obviating the need for bone grafting.
3. Bicortical stabilization can be more easily achieved. Longer, tilted implants make residual cortical bone more accessible resulting in greater primary stability.
4. Angled implants provide secondary resistance to vertical displacement by virtue of their nonaxial, oblique position in the archform which is perpendicular to occlusal forces. This stabilization is separate from insertional torque and is only enhanced by cross-arch stabilization
5. Distal cantilevers are minimized when a more posterior emergence of distal implants is achieved resulting in greater biomechanical stability.
6. Anteroposterior spread (AP spread) is enhanced.
7. An alternative treatment option for patients with severe systemic conditions which may render them poor candidates for bone grafting.

ALL-ON-FOUR® HISTORY

In 1991 and 1992, Bruggenkate published reports of angled implant placement in the posterior maxilla used to support overdentures.[4,5] In 1995, a one-year primate study performed by Celletti et. al. demonstrated osseointegration of both straight and angled implants. This study provided both clinical and histologic evidence of implant osseointegration irrespective of implant angulation.[6]

In 1995, Brånemark published a 10-year survival study of fixed prostheses retained with either four or six implants. This article suggested that, although there was a tendency for increased failure rates in patients with only 4 implants, the overall survival rate for both implants and prostheses was the same for both groups. Prior to this publication, the tendency of some clinicians was to place as many maxillary implants as possible in cases of full-arch rehabilitation.[7] This publication was the first to demonstrate equal success with an implant foundation consisting of only 4 implants.

A graftless surgical technique and medium-length study using angled implants was published by Mattsson et. al. in 1999.[8] This solution to maxillary full-arch rehabilitation was postulated to increase treatment predictability, decrease patient cost, and decrease complication rates. 86 implants were placed into 15 patients. Patients were followed for an average of 45 months. During this time, one implant was lost resulting in a 98.8% implant survival rate. All patients had a stable prosthesis at the end of the observation period. Bilateral fenestrations were created into the maxillary sinuses for the purpose of anatomic exploration and bone sounding of the anteromedial sinus wall. Posterior implants were placed parallel to the sinus walls. Anterior implants were placed axially. Eighty-eight percent of implants installed had 2-5 exposed palatal threads which were not grafted. This finding did not seem to lead to any mucosal problems or marginal bone resorption according to their report. Primary closure was obtained at the time of surgery. In this study, patients were not allowed to wear a removable prosthesis for 2 weeks. Implants were uncovered at 6 months. The authors concluded that the maximum use of residual bone stock, angulation of implants, and exposed palatal implant threads may allow for full-arch rehabilitation of severely resorbed maxillas.

In 2000, Krekmanov reported placement of angled implants in severely resorbed maxillas.[9,10] An open sinus technique was performed by way of a sinus fenestration, and a straight probe was used to sound the anterior and posterior walls of the sinus. Implants were placed parallel to the anterior and posterior walls at approximately 30-degree angulations. A total of 75 maxillary implants were placed and followed for 18 months. Nineteen implants were palatally inclined and placed tangential to the curve of the palate at the molar regions engaging maximum cortical bone. During the observed time period only one maxillary implant was lost.

In 2001, Aparicio et. al.[11] used a combination of angled and axial implants as an alternative to sinus grafting in patients with severe maxillary resorption. Implant surgery was two-stage with burying of implant fixtures at the time of surgery. Final restorations consisted of fixed partial prostheses. Twenty-five patients were followed for an average of 37 months (up to 5 years). Residual dense bone was engaged by angling implants parallel with the anterior and posterior walls of the sinus. In these instances, posterior implants found apical stabilization in the pterygomaxillary region, and anterior implants were apically stabilized at the piriform. In other instances, the curvature of the palatal vault was apically engaged. A total of 101 implants were placed. The overall prosthesis survival rate was 100%. Tilted implants had a survival rate of 100%. Axial implants had a survival rate of 96.5%.

At the time, these studies represented a subset of those available in the body of literature that suggested axial and tilted implants had comparable success in short and medium-length follow-up periods. Still, surgeries were two-stage with healing periods of 6-8 months before implant loading. Advances in implant design and surface coatings aimed to reduce healing time and increase bone-to-implant contact. It was found that implant roughness, porosity, topography, and surface energy were synergistic accelerators of osteointegration. Anodization of implant surfaces as well as air powered particle abrasion followed by acid washings were two techniques manufacturers employed to increase microtexturing of implant surfaces.[12-18]

In accordance with original principles of osseointegration, implants were placed and buried beneath the soft tissue for a healing period to prevent excessive movement. Studies later emerged showing that limited movement could be tolerated without disintegration of the implant.[19,20] This finding was perhaps best reported by Schnitman et. al.[21] in 1990. In an attempt to provide his patients with a fixed provisional appliance during the healing phase following surgery, seven or more mandibular implants were placed at the time of surgery. Three implants were used to fixate an immediate provisional appliance while the remaining implants were buried throughout the healing phase. A surprising discovery was that more than 90% of the provisional implants remained integrated throughout the treatment phase. A 10-year follow-up study published in 1997 demonstrated that more than 80% of those original provisional implants remained osseointegrated.[22] Tolerability of a certain amount of implant micromovement during the healing phase was not detrimental to overall survivability.

Having determined that implants could be placed in both axial and tilted orientations with equal success and knowing that full-arch rehabilitation could be achieved with 4 implants, the next logical question was the plausibility of immediate function full-arch rehabilitation.

Immediate loading of angled and axial implants was first reported in the mandible and later in the maxilla.[23-25] Maló performed immediate full-arch rehabilitation of 32 patients with 128 implants and documented his success in a one-year retrospective study. His study highlighted the use of four implants placed at the cornerstones of the maxillary arch. Anterior implants were placed in axial positions while posterior implants were angled 30-45 degrees and parallel with the anterior sinus wall. The maxillary sinus was fenestrated bilaterally and probed to ensure placement of implants within residual bone and with maximal anteroposterior spread. Insertional torque of at least 40 Ncm was obtained by underpreparing implant osteotomy sites and relying on lateral compression of implant threads and bicortical stabilization. Implants were loaded with a fixed provisional restoration on the day of surgery. Final protheses were delivered 12 months after surgery. No axial implants failed, and three tilted implants failed resulting in survival rates of 100% for axial implants and 95.3% for tilted implants.[25]

Medium and long-term follow-up studies published by Maló corroborated original findings with similar levels of success.[26]

MAXILLARY ALL-ON-FOUR® SUCCESS

Numerous studies have corroborated the success of full-arch implant supported rehabilitation utilizing 4 angled implants. Chrcanovic et. al.[27] compared tilted and axially placed implants in a meta-analysis which included both maxillary and mandibular implants. The authors compared implant failure and marginal bone loss based on implant angulation. Forty-four publications were included in their study with 5,732 axial implants and 5,027 tiled implants. There wasn't any statistically significant difference in implant failure rates or marginal bone loss between the groups.

In a similar meta-analysis comparing tiled and axial implants utilized in immediate function full-arch rehabilitation of the maxilla, Menini et. al.[28] reported on 1,623 maxillary implants placed into 324 patients. Of these, 47.9% were tiled and 52.1% were axial. Again, there wasn't any difference between implant survivability and marginal bone loss between the groups.

Ata-Ali et. al.[29] performed three meta-analyses on axial and tilted implants. Their analysis included 13 publications with implants placed in both maxillary and mandibular arches. They investigated 7 retrospective studies and 6 prospective studies. There wasn't any difference in success rates between retrospective and prospective studies. There wasn't any statistically significant difference in marginal bone loss or implant survival between axial and tilted implants.

A significant limitation of any meta-analysis is variability of surgical technique, number of operators, and operator experience. A 2017 retrospective study compared marginal bone loss and implant success between axial and tilted implants placed in the maxilla in accordance with the All-on-Four® protocol at the Maló Clinic[30]; 891 patients were rehabilitated with 3,564 maxillary implants for 5 years. Overall implant success was 96%. Success rates for tilted and axial implants were 96.1% and 95.7%, respectively. Marginal bone loss was measured using periapical radiographs at the time of surgery and after 5 years of function. Axial and tilted implants showed mean bone loss values of 1.14±0.71 mm (range 0-6.9 mm) and 1.19±0.82 mm (range 0-8.4 mm), respectively. Three percent of all implants showed marginal bone loss of <0.2 mm; while 12% showed more than 2 mm of marginal bone loss. Advanced marginal bone loss (>2.8 mm) occurred in 4% of the implants and was attributed to biological and mechanical complications. With regard to advanced marginal bone loss, a slight but statistically significant higher proportion of complications occurred with tilted implants as compared to axial implants. Smokers and female patients exhibited a 2-fold increased risk for advanced bone loss. Overall, linear mixed model analysis from this study showed that implant orientation does not significantly contribute to peri-implant bone loss or implant success after 5 years. Survival rates of axial and tilted implants range from 95-100%.

MAXILLARY AGE-RELATED CHANGES

In general, the pattern of maxillary bone resorption progresses in a predictable fashion with remodeling of the horizontal and vertical dimensions occurring first followed by morphologic changes of underlying basal bone. In a randomized, cross-sectional study of 300 dried human skulls, Cawood and Howell observed dimensional changes of edentulous jaws and translated their findings into a classification system still used today.[31] There are 6 classes. Class I jaws are dentate with supporting alveolar bone. Class VI jaws show loss of all supporting alveolar bone with atrophy of basal bone. Following dental extractions, diminutive changes in the horizontal dimension are observed first followed by vertical bone loss. These patterns correspond with Cawood and Howell Class III and IV maxillas, respectively. Underlying basal bone is more resistant to progressive resorption. Residual flat and then depressed alveolar ridgeforms correspond with Cawood and Howell Class V and VI maxillas. These patterns of resorption give the impression of a maxilla that narrows posteriorly while retruding in an AP dimension, all with concomitant loss of vertical height. Simultaneous patterns of mandibular resorption result in a progressive pseudo class III jaw relationship and a concave facial profile.

Rate of alveolar bone loss and time are not a linear relationship. In a study observing reduction of the alveolar ridge in patients wearing conventional dentures, Tallgren[32] observed the greatest dimensional changes occurred within the first year of edentulism.

Pneumatization of the maxillary sinuses following dental extractions further contributes to dimensional changes of the maxillofacial complex. Subantral bone mass is lost first followed by a decrease in bone mass between the sinus and nasal cavities. This is best observed on orthopantomography.[33]

Anatomic regions most resistant to atrophy are the natural maxillofacial buttresses (**Figure 1**). These sites are subjected to continued load-bearing forces throughout life. Cortical bone in the piriform regions, pterygomaxillary regions, zygomaticomaxillary regions, and midline nasal crest are often the most resistant to atrophy.[33-35]

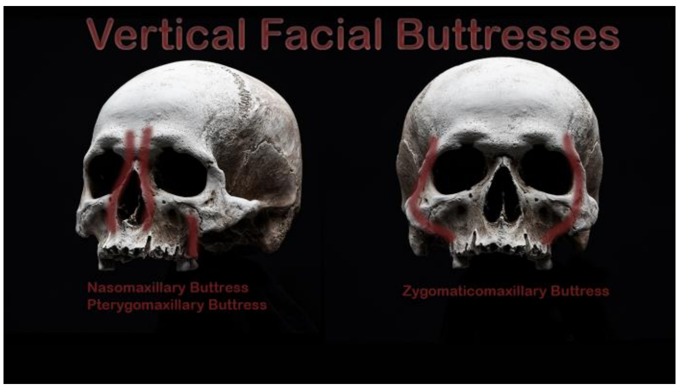


Figure 1: *Vertical facial buttresses.*

CLINICAL PATIENT ASSESSMENT

Successful All-on-Four® rehabilitation is a complex, patient-tailored, and prosthetically-driven treatment solution. Prosthetic material, teeth size, lip support, incisor positioning, teeth show at rest and animation, phonetics, orofacial musculature, bite force, parafunctional habits, and alterations to the occlusal vertical dimension are just some of the factors used to determine interarch prosthetic space requirements by the restorative clinician. Many of these treatment planning parameters are beyond the scope of this paper. In all cases, the final prosthetic design dictates the vertical position of the maxillary osteotomy which, in turn, directs functional implant positions and angulations. The vertical position of the maxillary osteotomy after extractions and alveolar reduction is sometimes referred to as the "All-on-Four® Shelf".[46]

At a minimum, 15 mm of vertical space per arch is needed to meet prosthetic space requirements. Any less than this vertical requirement greatly weakens both the interim and final prostheses. Significant patient variability exists among All-on-Four® candidates. For some, this requirement will necessitate teeth removal and significant alveolar bone reduction. In others, years of edentulism and progressive atrophy may require very little alveolar recontouring at the time of surgery.

It is equally important that the interface between the prosthesis and the residual ridge, often termed the "transition zone",[47] be concealed when the patient's lip is at rest and during a full, animated smile. Inadequate alveolar reduction can result in catastrophic esthetic outcomes, particularly in patients with a high smile line.

RADIOGRAPHIC ASSESSMENT

An initial, cursory appreciation of bone volume and overall dental condition can easily be obtained with an orthopantomogram or panoramic reconstruction of an CBCT. As part of a presurgical method for evaluating bone volume in maxillary full-arch rehabilitation, Bedrossian et. al.[47] advocated the visual division of the maxilla into 3 zones.

According to this classification, Zone 1 is defined as the intercanine region. Zone 2 is the premolar region, and Zone 3 is the molar region. Ample bone present in all 3 zones implies that axial implants can be placed anywhere in the arch. Residual bone present in zones 1 and 2 is amendable to tilted posterior implants inclined to avoid the anterior wall of the maxillary sinus. The presence of bone only in zone 1 makes posterior implant support difficult to achieve. In these instances, a transantral approach may be considered if sufficient subantral bone is present for crestal stability. If not, apical fixation in more distant anatomic sites such as the zygoma or pterygoid process may be considered. Finally, in cases where no substantial bone is present in all three zones, graftless implant rehabilitation requires sole fixation in the zygomas, pterygoid processes, and the midline nasal crest.

Preliminary radiographic evaluation should be visualized at the vertical level of the proposed maxillary osteotomy. Often, the reduction of subantral and subnasal alveolar bone places the future All-on-Four shelf® in close proximity to the sinus and nasal cavities while decreasing the amount of vertical bone available for fixation. As mentioned previously, the vertical position of the All-on-Four® shelf is ultimately defined by the prosthetic treatment plan. However, a series of simple radiographic measurements can be used to approximate its position for the purpose of a more accurate preoperative radiographic assessment.

The patient's maxillary midline is centered on a sagittal view of the patient's CBCT. A 15-16 mm line is scribed apically from the incisal edge of a central incisor (**Figure 2**). The apical position of this measurement represents the possible vertical position of the future All-on-Four® shelf. However, numerous patient factors may necessitate further apical or coronal transposition of this proposed osteotomy level. Among these factor are incisal wear, loss of OVD, and hyper-eruption of the anterior dentoalveolar segment. The proposed shelf is often best visualized on the CBCT reconstructed panoramic view by scribing a horizontal line at the proposed osteotomy level. Sinus proximity, anatomic limitations, and residual bone at this level are now more easily compared (**Figure 3**).

Figure 2: *Proposed reduction measured from incisal edge of central incisor.*

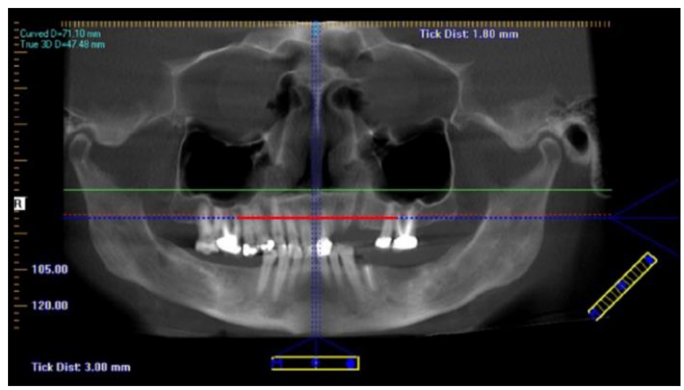
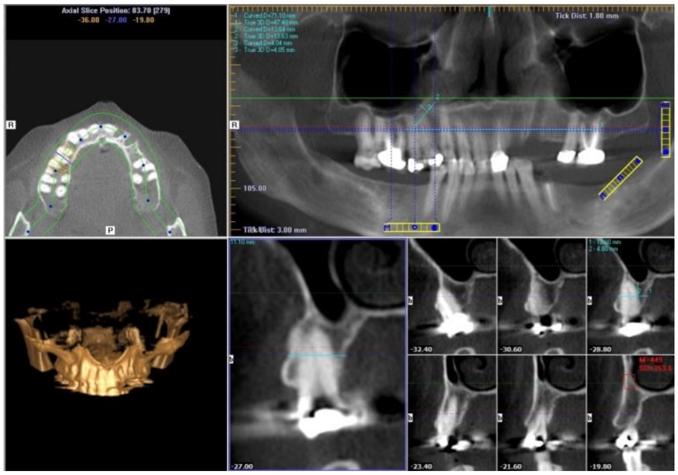


Figure 3: *Proposed vertical level of maxillary osteotomy outlined in red.*

Proposed positions of posterior implants are now assessed. 30-degree posterior implants are planned so as to avoid the anterior extent of the maxillary sinus. Crestal and apical bone quality is radiographically evaluated. Trabecular bone patterns, the amount of cortical versus cancellous bone quantity, and relative amounts of bone mineralization can help guide ideal implant entry and apical fixation points. Bone density can be estimated by measuring Hounsfield units. However, inherent limitations of the Hounsfield scale imposed by using a

CBCT as opposed to a medical-grade CT should be remembered. Numeric values are only relative approximations of bone density. Implant lengths needed to engage dense paranasal bone are noted. Potential anterior implant sites are similarly evaluated with entry points at the lateral incisor regions, 17-30-degree posterolateral angulations, and apical fixation in the dense paranasal bone (**Figures 4A-C**).



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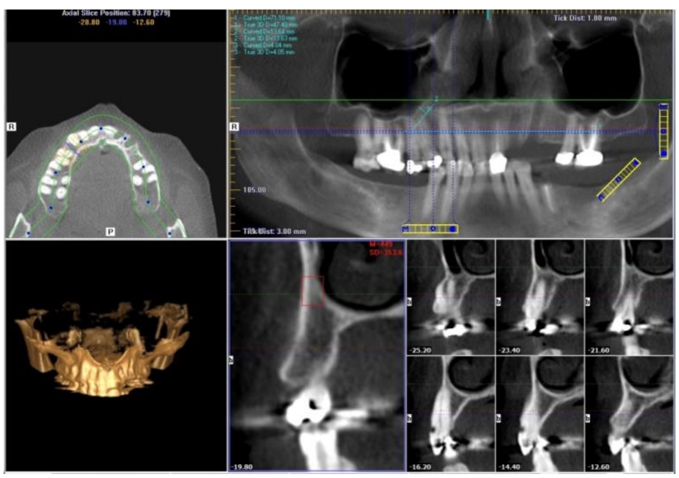

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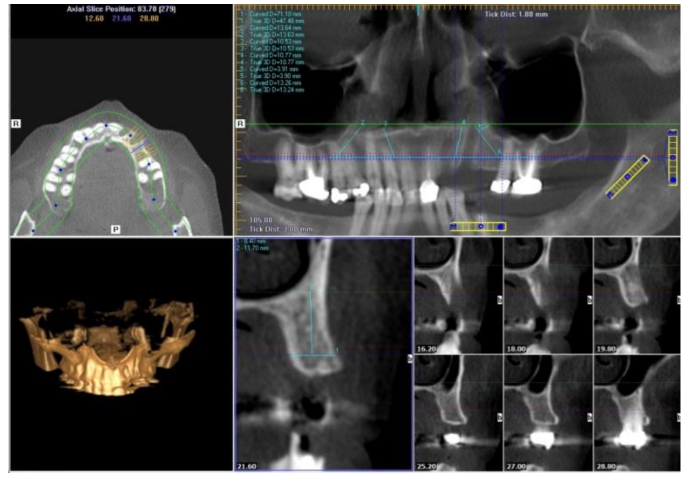


C)

Figure 4: ***A****, Proposed entry point and angulation of posterior implant. CBCT shows entry point at the second premolar position with 30 degree angulation with avoidance of maxillary sinus.* ***B****, Proposed apical fixation point of posterior implant. Apex is fixated in dense cortical bone of the right piriform.* ***C****, All proposed maxillary implant positions and lengths.*

With tentative implant positions in place, AP spread is evaluated next and best measured using axial slices of the CBCT at the level of the vertical osteotomy (**Figure 5**).

Figure 5: *AP spread at the level of the proposed osteotomy can be measured on axial slices of the patient's CBCT. Class A/B maxillas usually have a posterior entrance points 25-27mm from the midline.*

AP spread must be deemed adequate for biomechanical support with efforts to minimize distal cantilevers to 1.5 times the AP dimension or less. Proposed dental extractions and alveolar reduction must be in harmony with requirements from the final prosthodontic treatment plan. Once confirmed, a significant amount of information can be gleaned from this radiographic treatment plan. Knowing the vertical position of the All-on-Four® Shelf prior to surgery offers many benefits. The vertical reduction line can be translated intraoperatively with a caliper using the incisal edges of residual teeth as reliable and reproducible landmarks. Similarly, anterior and posterior implant entrance points can be translated to the operating arch using a caliper and the anatomic midline as a reference.

The CBCT remains the primary imaging modality for All-on-Four® treatment planning. Perhaps its greatest limitation, the ability to accurately assess bone quality, remains the greatest challenge for cases where immediate function is desired. Primary implant stability is a function of both residual bone quality and quantity.

MAXILLARY ARCH CLASSIFICATION

Preoperative radiographic assessment may show adequate bone volume for implant placement. However, hollow medullary spaces, poor bone density, and lack of cortical bone may contribute to an overall poor bone quality making primary fixation difficult to achieve. Conversely, a ridge with moderate to severe atrophy may have diminished bone volume but sufficient cortical bone to allow for strong primary implant fixation.

With progressive bone atrophy, sufficient mechanical fixation is often derived from apical and crestal cortical bone which may not be apparent until alveolar reduction has been accomplished. Jensen[48] proposed an All-on-Four®, immediate-loading site-classification which takes into account the presence of load-bearing bone for implant fixation. Where other classifications have focused on the preoperative assessment of available bone, this classification system is applied intraoperatively after alveolar bone reduction with the goal of apical fixation in strong cortical bone for immediate function. Anterior implant angulations are also treated differently in this scheme. Vertical placement of anterior implants was traditionally reported.[25,26] This classification advocates angling anterior implants up to 30 degrees in an effort to engage strong, cortical bone in cases of atrophy when subantral bone volume has diminished to less than 10 mm. This immediate-loading classification was derived from a study of 100 consecutive arches which were classified after bone reduction and then treated with an immediate function All-on-Four®. Arches were classified as Class A-D. Characteristics associated with each class act as an intraoperative road map and drive functional implant placement at the time of surgery.

The All-on-Four® shelf has many benefits first published by Jensen et. al.[46] (**Figure 6**).

1. Creates prosthetic restorative space
    a. A minimum of 15mm is needed
2. Establishes the alveolar plane
    a. Reestablishment of an alveolar plane parallel with the interpupillary line and the Frankfort horizontal is created
3. Shelf width determines implant diameter selection
4. Shelf reduction approximates piriform bone fixation
5. Shelf findings suggest convergent or divergent implant placement strategy

6. Establishes optimal osseous sites for implant placement
7. Defines secondary fall back sites for implant placement
8. Exposes palatal plate cortical anatomy for implant fixation
9. Facilitates posterior implant placement (AP spread) in relation to anterior sinus wall
10. Provides bone stock for bone grafting

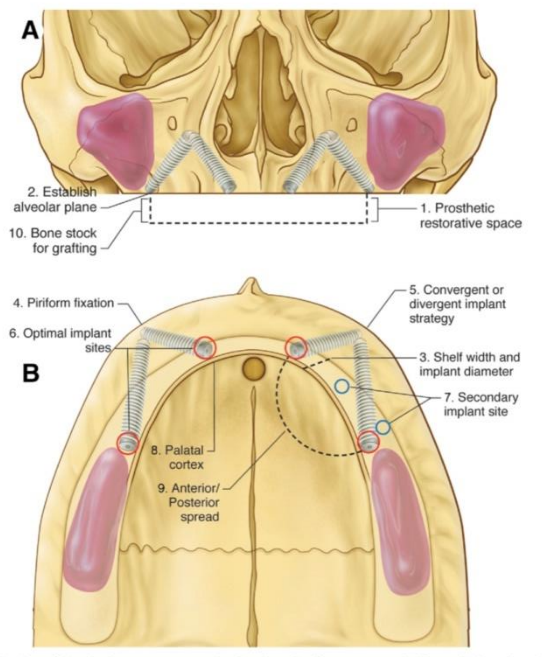
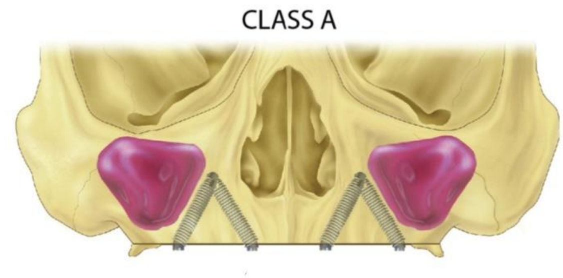


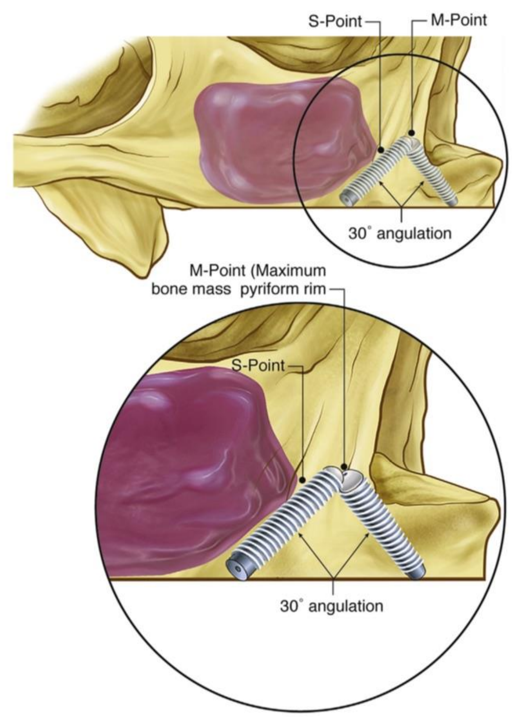
Figure 6: *Technical advantages of All-on-Four® Shelf.*

Class A

Class A maxillas are associated with thick palatal cortical bone usually just anterior and medial to the palatal root of the maxillary first molar. Initial twist drills may be entered at this point and angled anteriorly between 30 and 45 degrees. Often, the palatal shelf can be grooved with sequential twist drills. Depending on bone quality, the trajectory of the implant can either be directed anteriorly within the body of the alveolus, or it may pass in a transalveolar trajectory. The anterior point of apical fixation is the cortical bone mass of the lateral piriform rim. Anterior implants are placed 20 mm or more forward in the arch and angled posteriorly. Four implants oriented in this fashion create a characteristic M-shape when viewed on a radiograph. Very little cantilever is required for the restoration. An AP spread of 20 mm is possible with an interimplant arch span of greater than 60mm (**Figures 7A, B**).



A)



B)

Figure 7: A*, Class A Maxilla with angulation of all 4 implants resulting in characteristic "M" pattern. AP spread up to 20 mm. Interimplant arch span >60 mm.* ***B****, Convergence of implants at "M" point defined as the point of maximum bone mass at the piriform rim. S-Point refers to "Sinus Point", or the anterior most point of the maxillary sinus.*

With Class A maxillae, sufficient bone mass remains at the lateral piriform buttress to allow fixation of all four implant apices. This site of maximum bone mass found lateral and superior to the nasal fossa is termed “M-point” and is the workhorse for All-on-Four® implant fixation.[1,33,48-50] Forty-eight percent of patients were classified as Class A.[48]

Class B

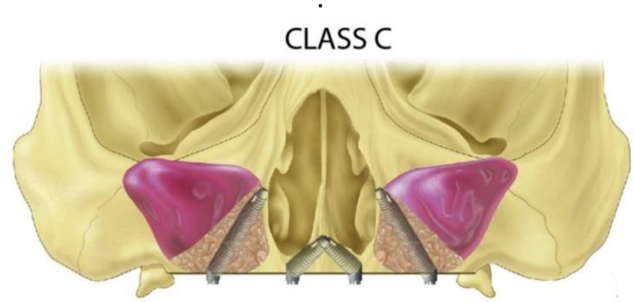
Class B maxillas show signs of moderate atrophy. Thinning of the palatal shelf and pneumatization of the sinuses require posterior implants be placed anterior to the sinuses and usually enter the ridge at the second premolar sites. Anterior implants are placed in the lateral incisor/canine regions. All implants are angled and engage M-point. AP spread is approximately 15 mm. Interimplant arch span is 45-55 mm. 35% of patients were classified as Class B.[48] (**Figure 8**)

Figure 8: *Class B Maxilla. Moderate atrophy. AP spread ≥15 mm. Interimplant arch span 45-55 mm.*

Both Class A and Class B maxillas can be treated with an implant placement strategy termed the "M-4" and represent the vast majority (83%) of maxillas according to Jensen's study. The characteristic shape of an "M" observed radiographically is achieved by tilting anterior implants and providing them with the same mechanical advantages as posterior tiled implants: increased length despite limited vertical bone availability, increased AP spread, decreased need for bone grafting, increased insertion torque, and an increased resistance to vertical displacement. At least 5-8 mm of vertical bone in the anterior maxilla is needed to be able to place a 10-13 mm implant into the lateral piriform rim.[1] This anterior angled implant strategy achieves a superior mechanical advantage with added vertical resistance to displacement when compared to an implant placed in an axial orientation. This surgical principle parallels toenailing techniques employed regularly in carpentry where nails are driven at an angle to better resist displacing forces.

Class C

Class C Maxillas show continued loss of subnasal and subantral bone mass with increased pneumatization of the maxillary sinuses. Posterior implants may have to enter the crest of the ridge at first/second premolar sites with anterior fixation at M point. If sufficient cortical bone exists, anterior implants also may obtain apical fixation at M point. Moderate to severe atrophy may result in thinning of the paranasal bone such that only 1-2 mm of thickness remains. This anatomic limitation will only allow apical fixation of posterior implants. In these instances, anterior implants may be angled 30 degrees and directed anteriorly towards the midline bone mass. The midline nasal crest of the maxilla is an area of dense bone resistant to atrophy and may serve as a good point for apical fixation of 1-2 implants in cases of severe atrophy. This bone mass it termed "V-point" for the Vomer which articulates with the maxillary nasal crest in this region. This pattern of implant placement with all 4 implants directed 30 degrees to the anterior is termed V-4 due to its radiographic appearance of an inverted "V".[34, 35, 51] This technique can be performed as long as 4-5 mm of subnasal bone is available (**Figures 9A, B**).



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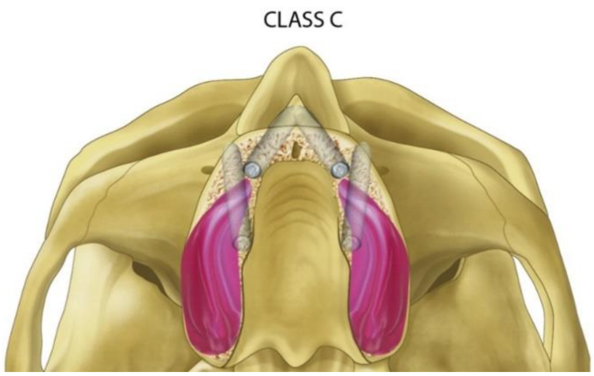


B)

***Figure 9: A**, Class C Maxilla: Moderate-Severe atrophy. 12-15 mm AP spread obtainable with 40-45 interimplant arch span. **B**, Class C maxilla showing midline convergence of anterior implants engaging "V-point".*

Progressive pneumatization of the maxillary sinuses is also a characteristic of the Class C maxilla. The sinus may extend anteriorly past the canine and sometimes even to the position of the central incisor root apices. In these cases, posterior implant placement may be performed in conjunction with anterior sinus elevation provided that support can be obtained crestally as well as apically at M-point. The body of the implants are predictably passed transantrally under direct visualization through a 10mm sinus antrostomy following limited reflection of the sinus membrane.[34,51,52] Posterior implants placed in this fashion are often 16-18 mm in length and can obtain high primary insertional torque due to bicortical anchorage. The interpositional implant body may then be grafted at the surgeon's discretion (**Figure 10**).

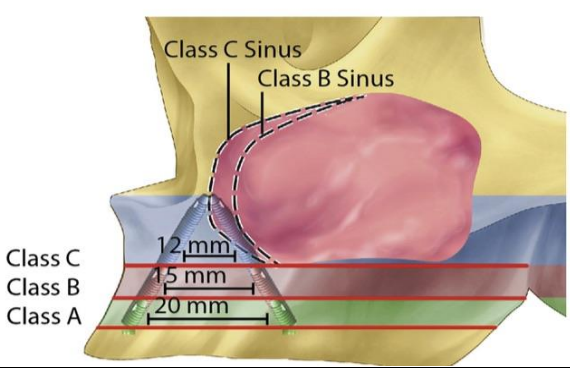


***Figure 10:** Comparisons of AP spreads obtainable with Class A, B, and C Maxillas.*

Despite anatomic limitations, an AP spread of 12-15 mm and an interimplant distance of 40-45mm can still be obtained with Class C maxilla. 13% of patients were classified as Class C.[48]

Class D maxillas often have bone remaining only at the midline nasal crest. The residual alveolus consists of thin cortical bone and has an "egg shell" radiographic appearance. Two anterior midline implants may be passed into V-point. Posterior graftless solutions require use of zygomatic implants or pterygoid implants for support. Only 2% of patients were classified as Class D.[48] (**Figure 11**).

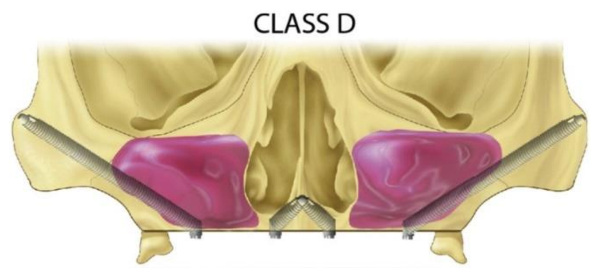


***Figure 11:** Class D Maxilla.*

All-on-Four® candidates present with a diverse range of clinical and radiographic challenges. Dentoalveolar defects vary from tooth-only defects to complete loss of supporting alveolar bone. With immediate loading protocols, this wide array of patient anatomy can often be functionally categorized into 4 classes which act as an intraoperative road map for subsequent implant placement strategies. Patients with terminal dentitions and various stages of atrophy can often be treated with either an M-4 or V-4 placement strategy. Even in cases where sufficient alveolar bone exists for axial implant placement, higher predictability, greater insertional torque, and better primary stability are often obtained by employing an angled technique for all implants.

ADDRESSING VERTICAL AND HORIZONTAL DEFICIENCIES IN THE ALVEOLAR RIDGE

Restrictions on implant length imposed by vertical deficiencies may be circumvented by placing tilted implants as previously addressed. Angulations of 17-30 degrees in the anterior maxilla and 30-45 degrees in the posterior maxilla maximize use of available bone volume.

As atrophy of the horizontal alveolar dimension progresses to less than 4 mm, placement of implants fully surrounded by residual bone is challenging. Surgical options include the use of narrow diameter implants, staged or simultaneous horizontal bone augmentation, or palatal placement of implants with palatal thread exposure.

Placement of implants palatal to the horizontally deficient alveolar crest has shown promising results in medium and long-term studies.[8,9,36-39] Placement with this strategy results in good primary stability, preservation of the buccal crest, and 2-5 exposed palatal threads which may be grafted at the discretion of the surgeon. Studies have demonstrated comparable success rates whether exposed threads are grafted or not. Peri-implant bone loss reported with this technique is comparable with other studies and in line with recommendations of acceptable levels of peri-implant bone loss originally proposed by Albrektsson et. al.[40] in 1986. This could be explained by the fact that horizontal bone loss following dental extractions proceeds more rapidly and to a greater extent from buccal to palatal[41] suggesting that palatal positioning, in cases of compromised alveolar width dimensions, may be an acceptable alternative.

In a long-term retrospective study spanning 8-12 years, Rosen and Gynther[36] rehabilitated 19 patients with severe maxillary horizontal deficiencies; 103 implants were placed in a two-stage surgical protocol. Posterior implants were tilted. Horizontal ridge deficiency required that anterior implants be positioned palatally with 2-5 exposed crestal threads. Bone grafting was not performed in conjunction with implant placement. A temporary complete denture was provided during the healing phase after which a fixed, full-arch appliance was delivered. The authors reported an overall implant success rate of 97% after an average follow-up period of 10 years. Average peri-implant bone loss was 1.2 mm. Forty-seven percent of patients exhibited mucositis which the authors attributed to hygiene difficulties imposed by the prosthetic design. There were no reported cases of peri-implantitis.

In a similar 5-year retrospective study, Peñarrocha-Oltra et. al.[38] demonstrated comparable results with a similar technique. Thirty-three patients were treated with 151 palatally positioned implants. Particulate graft was adapted to exposed palatal threads at the time of surgery. A two-staged surgery was performed. After healing, patients were treated with a fixed, full-arch prosthesis. Overall success of palatal implants was 98.7% during the 5-year interval. Average peri-implant bone loss was 1.03±1.28 mm. Mucositis was found in 20.8% of the implants. There were no reported instances of peri-implantitis. Average peri-implant probing depths conducted during this study were reported to be 2.89±0.77 mm with no significant differences between the buccal and palatal of implants.

PERFORATION OF SINUS MEMBRANE

The Maxillary All-on-Four® surgical technique and the use of tilted implants provides a surgical technique that avoids the maxillary sinuses. However, technical demands during surgery often result in perforation of the Schneiderian membrane that may be intentional or iatrogenic. Discussion of membrane perforation and its potential sequalae on implant integration is warranted.

Intentional penetration of the nasal and sinus membranes at the time of implant placement was reported by Brånemark et. al.[42] in 1984 to have comparable success with maxillary implants that did not perforate the membrane.

A 2016 experimental study on the penetration of dental implants into the maxillary sinus at different depths showed similar results.[43] In a radiographic and histologic study, 8 implants were placed into 4 healthy female dogs immediately after extraction of first molars. The dogs were placed into 4 groups based on the depth of implant protrusion into the maxillary sinus. Implant osteotomies were then performed with rotary instruments through palatal root sockets. There was no attempt to preserve the integrity of the sinus membrane during preparation. The width of each perforation was the 4.5 mm diameter of the bur. Implants were then placed with 0, 1, 2, and 3 mm protrusion into the maxillary sinus. Dogs were sacrificed after 5 months. CBCT and histologic analysis were performed. All implant sites showed healing after 5 months with no differences in implant stability. Implants that protruded 0, 1, and 2 mm into the maxillary sinus showed histologic evidence of bone coverage. Implants with 3 mm protrusion lacked complete bone coverage and were associated with mucosal thickening of the sinus membrane. Results of this study were consistent with reports by Jung et. al.[44] that showed complete healing and sinus mucosal coverage of dental implants protruding <2 mm into the sinus of mongrel dogs. Mucosal thickening was associated with implants protruding >4 mm into the sinus.

Perforation of the sinus membrane is a common complication during sinus augmentation procedures occurring between 7-35% of the time and is highly dependent on several factors including surgical technique, surgical experience, and numerous host factors.[43] The extent to which Schneiderian membrane perforation may have a detrimental effect on implant success is a controversial topic in the literature. Some reports indicate no statistically significant correlation, and others report an increase in implant failure.[45]

A 2018 systematic review and meta regression analysis addressed the topic of intraoperative sinus membrane perforation during sinus lift surgery and its correlation with implant failure. There were 58 studies included, and 2,947 patients were treated with 3,884 maxillary sinus augmentations and 7,358 dental implants. When comparing implant failure at perforated sinuses versus unperforated sinuses, implant failure was found to be higher (10.3%) when associated with perforated sites as compared to unperforated sites (2.4%). Results from this meta-analysis suggest that intraoperative perforation of the Schneiderian membrane could result in increased implant failure.

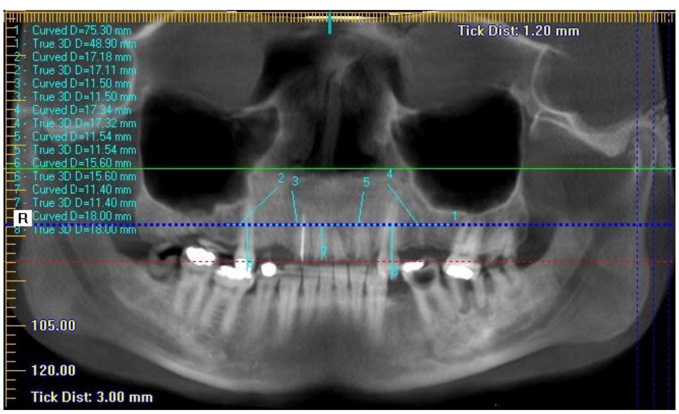
Traditional All-on-Four® surgery is graftless with some exceptions making a direct comparison with many studies in the body of literature difficult. The presence of a sinus graft is an added variable with potential for additional complications.

SURGICAL STEPS

There are numerous ways All-on-Four® surgery can be performed. The following steps detail the sequence and rationale used by the author in private practice. (**Figures 12 A-C**)

A)

B)



C)

***Figure 12:** **A**, Preoperative clinical photos. **B**, Preoperative intraoral photographs. **C**, Preoperative radiographic treatment plan highlighting implant placement, lengths, angulations, and proposed alveolar.*

The procedure begins with preoperative measurements of the patient's VDO and nose to incisor position.

Local anesthesia with epinephrine is infiltrated facially within the maxillary vestibule. Bilateral PSA, greater palatine, and infraorbital nerve blocks are performed. Vestibular infiltration is extended superiorly to the point of the nasal aperture. A nasopalatine block is performed.

The incision design varies depending on the anticipated amount of reduction as well as the thickness of facial keratinized tissue. The incision design and location should be anticipatory of the final soft tissue position. In the premaxilla, the incision is beveled approximately 45 degrees and placed to allow at least 2 mm of facial keratinized tissue for closure. Utilization of this design when possible avoids reflection of tenacious circumdental gingival fibers and facilities easier apical reflection of the mucoperiosteal flap while ensuring sufficient keratinized tissue is maintained facial to future implant sites. At the distal of the canine, the incision is transitioned to an unbeveled sulcular incision and continued posteriorly. Buccal releasing incisions are placed at the molar sites.

A full thickness mucoperiosteal flap is then elevated. Reflection in the anterior is carried out to the base of the piriform aperture. The reason for this is two-fold. First, it permits direct visualization of remaining bone height during alveolar reduction. This precaution acts to prevent inadvertent over-reduction. Second, it provides access for reflection of nasal mucosa. This is necessary as atrophy progresses from moderate to severe. Residual cortical bone can be visualized more easily and sounded with proper direct visualization. Soft tissue reflection along the nasal floor and lateral nasal wall permits protection of mucosa with retractors during implant osteotomies and placement, especially in cases where a V-4 implant pattern is selected and midline bone is engaged.

Soft tissue reflection and exposure of paranasal bone is performed. This includes reflection of tenuous muscle attachments along the canine fossa and eminence. Visualization of this site is beneficial when determining anterior implant trajectories in patients with bimaxillary protrusion or significant facial undercuts/alveolar constrictions at lateral incisor sites. Direct visualization of this area also is helpful when preparing posterior implant osteotomies that are passed in a transalveolar manner as they are directed to M-point. The tip of the rotating instrument becomes visible as a shadow within the paranasal cortical bone during implant site preparation. This can alert the surgeon to the fact that ≤1mm of cortical bone remains and maximum bicortical stabilization can be achieved.

A caliper is then used to measure the proposed vertical alveolar reduction using the incisal edges of select teeth as reference points (**Figure 13**). This measurement is obtained from the restorative treatment plan and takes into account underlying bone anatomy, supraeruption of bone and teeth segments, planned changes in OVD, as well as mechanical/strength considerations that are patient specific. Usually, this vertical measurement is 15-17 mm from the incisal edge of the central incisors. Bone coronal to this line is planned for removal. A pencil is used to mark this reduction line on the alveolar bone. Facial bone coronal to this line can be removed with a reduction bur. Additionally, a fissure bur may be utilized to perform interdental osteotomies to facilitate less traumatic dental extractions. Teeth are elevated and extracted taking care to preserve the integrity of the remaining alveolar bone.

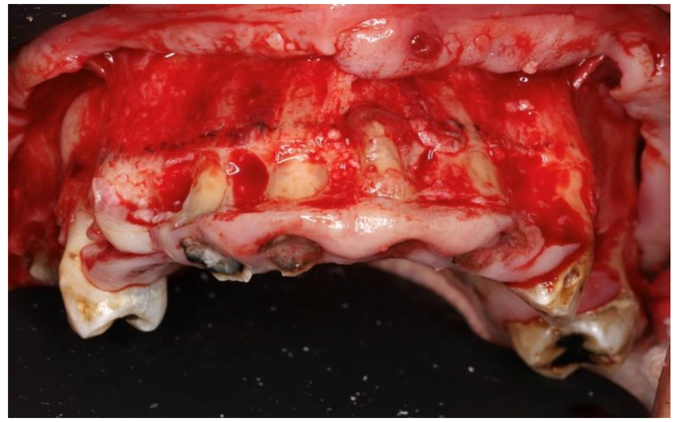


Figure 13: *Proposed vertical reduction line is marked with a pencil and facial bone coronal to this line is removed to facilitate easier extractions.*

The surgical guide is placed. The palatal portion of the guide provides a reproducible vertical stop. Alveolar reduction is verified/scribed with a pencil. (**Figure 14**).

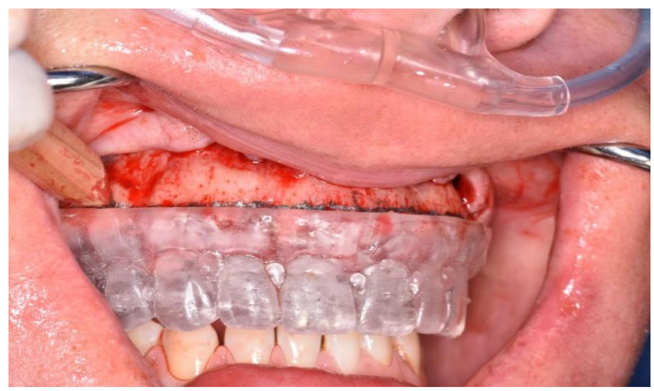


Figure 14: *A reduction guide may be placed after extractions to mark/verify reduction. (Photograph courtesy of Dr. Tom Berry)*

An incision along the palatal aspect of the alveolar ridge is planned. Depending on the amount of proposed reduction, this incision may be positioned more or less palatal. The alveolar ridge is generally more narrow in the anterior and widens posteriorly meaning that more palatal tissue may be excised in the anterior than in the posterior if primary closure is going to be obtained. Also, depending on the thickness of the posterior palatal tissue, the palatal incision may be beveled in the posterior to facilitate undermining and thinning of the palatal flap. Following the palatal incision, all intervening gingiva is removed with a ronguer. Palatal tissue is elevated with a periosteal elevator. A moistened, unfurled gauze may be used for finger dissection and further elevation of the palatal flap.

The All-on-Four® Shelf is created. An aggressive reduction bur, reciprocating saw, or fissure bur is used to reduce the alveolus to the proposed vertical level. Alveolar reduction is the first time the surgeon is afforded the opportunity to appreciate bone quality. A tactile sense of overall bone density is invaluable for implant osteotomy design and placement strategies. Cortical bone that is brittle with an inherent tendency to fracture during reduction will be prone to greenstick fractures when implant fixtures are placed. Hollow medullary bone with loose structural architecture will provide little primary stability and often cannot withstand repeated attempts at implant placement.

Pneumatization of the maxillary sinuses can be very prominent in the posterior maxilla with extension to the residual alveolar ridge. As a result, the vertical position of the All-on-Four® Shelf may be above the level of pneumatization making surgical encounter with the membrane inevitable. In these instances, posterior alveolar bone can be intruded into the maxillary sinus with osteotomes and membrane elevation. Alternatively, a crestal sinus lift can be performed. As the membrane is encountered, a series of sinus curettes are used to elevate the membrane. A collagen sponge can be placed to tent the membrane while alveolar reduction continues. Additionally, this access allows for bone sounding, probing, and measuring of the anteromedial walls of the sinuses to help determine implant trajectory and thickness of crestal bone at the time of placement.

A fox plane is placed on the shelf to verify parallelism with the interpupillary and Frankfort horizontal lines. A common mistake is insufficient posterior bone reduction resulting in either a thin posterior prosthesis that is prone to fracture or leveling of the occlusal plane producing the so-called “alligator bite”.[46] For this reason, verification with a fox plane is a critical step. Finally, the facial and palatal edges of the shelf are beveled with a rotary bur, and the ridge is smoothed with a bone file.

The ability to verify accurate reduction is critical for success of the interim and final prostheses. There are a number of reproducible measurements that can be gleaned from the radiographic treatment plan and transposed to the operating arch at the time of surgery to measure and verify alveolar reduction. A surgical/reduction guide may also be used. The following reproducible measurements and techniques aid the surgeon in placing and verifying the correct vertical position of the maxillary osteotomy.

1. The vertical dimension from the incisal edges of select teeth to the proposed osteotomy level
2. The vertical dimension from the piriform rim to the proposed osteotomy level
3. Residual extraction sockets can be probed and measured in relation to the proposed osteotomy level
4. The surgical guide may be placed to both mark the osteotomy level prior to reduction as well as very sufficient reduction
5. The fox plane helps to ensure leveling and sufficient posterior reduction

After alveolar reduction is verified, residual extraction sockets are curetted and cleaned of any remaining granulation tissue and debris. Facial or palatal flaps are curetted and mechanically debrided. All hard and soft tissues are irrigated with a peridex/saline solution.

Posterior implants must maximize AP spread while avoiding the sinus. Uncertainty regarding sinus proximity and residual subantral bone stock make identification of posterior points of entry challenging. Preoperative measurements obtained from axial CBCT slices at the level of the maxillary osteotomy can be transposed to the operating arch with a caliper measuring from the midline to the proposed point of entry. This point is scribed on the alveolar ridge with a pencil. For most Class A/B maxillae, this linear measurement from the midline is 25-27 mm. Numerous authors have recommended bone sounding of the anteromedial sinus wall and sinus floor to determine posterior implant entry points.[8,10,11,25] In these instances, access to the sinus is obtained by way of a small window or slot at the anterior inferior extent of pneumatization. If a crestal sinus lift was required during alveolar reduction no additional sinus access is required. Sinus anatomy can then be probed, measured, and scribed with a pencil. Transillumination of the sinus is also a reported technique to visualize anatomic boundaries.[53]

Posterior implant sites and associated anatomic limitations are the largest determinants of the final AP spread. When sequencing implant osteotomies and placement, posterior sites take priority. If for any reason, primary sites must be abandoned, secondary sites can be utilized as dictated by availability on the intraoperative All-on-Four® shelf.[46] The initial drill is placed on the ridge and pushed into the alveolus at the proposed point of entry. Tactile resistance encountered at this step will determine if the osteotomy can be directed through the middle of the ridge or if a transalveolar implant trajectory must be utilized to maximize palatal and piriform cortical bone. Often, maxillary cancellous bone is soft and readily compresses with mild tactile pressure applied at this step. When this occurs, sequential twist drills are used to groove the dense bone of the palatal cortex. The trajectory passes across the alveolus and finds secure bicortical fixation by apically engaging M-point. Posterior implants are angled 30-45 degrees (**Figure 15**).

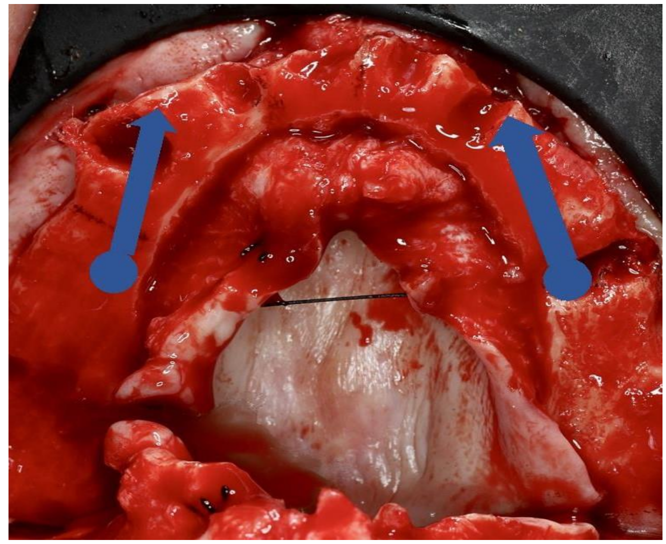


Figure 15: *Posterior implant entrance points are generally palatal, pass in a transalveolar fashion, and engage the dense cortical bone at "M-point".*

Anterior implant points of entry are at lateral incisor/canine sites and pass posterolaterally at 17-30 degrees to engage M-point. Some anatomic variants present with dense cortical bone just posterior to the central incisors that may be alternatively engaged. These implants are passed to M-point for apical fixation (**Figure 16**).

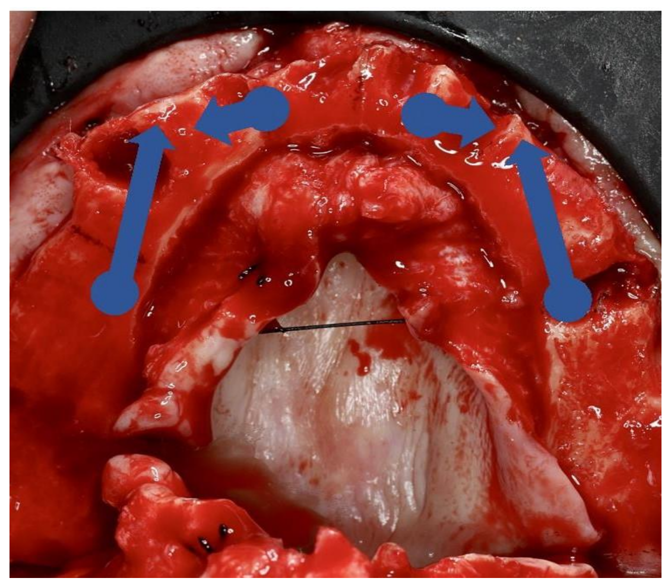


Figure 16: *Entrance points and trajectories for anterior implants.*

The All-on-Four® Shelf dictates implant width. In cases of a pronounced midalveolar constriction, additional vertical reduction may be indicated to permit adequate shelf width. This anatomic variant can be visualized as an hourglass shape when viewed on sagittal CBCT slices.

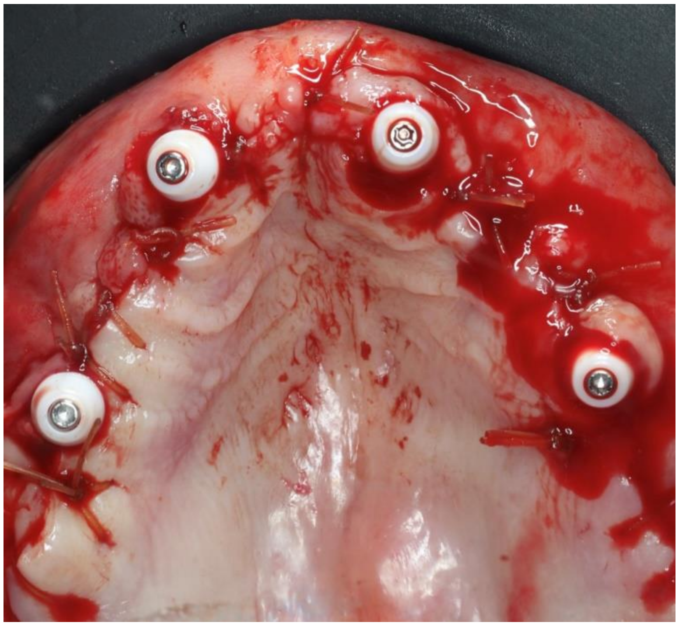
Differences in maxillary bone quality are highly variable. As a general rule, implant sites in D3/D4 bone should be underprepared in width but not in length. Malo used this technique when first attempting All-on-Four® with immediate temporization in the maxilla.[25] Implants with diameters greater than 4 mm were placed into sites prepared with a 2 mm twist drill. This resulted in improved primary stability due to compression along the lateral aspect of the implant bodies. Underpreparing the length of the implant osteotomy should generally not be performed. Cortical bone near the piriform is generally dense and most implants lack end-cutting properties. This combination results in a clinical situation where the surgeon notices a significant drop in torque during implant placement as the implant approaches final depth. Instead of apically engaging and advancing through dense cortical bone, the implant fixture spins in place because implant depth was not adequately prepared.

An opposite problem is encountered in dense maxillary bone where over compressive forces along the implant body can lead to greenstick fracture of the alveolus and a loss of primary stability. This problem is only augmented in patients with hollow, osteoporotic, medullary bone with accompanying dense, brittle, cortical walls that are highly prone to greenstick fractures. A tendency to underprepare the width of maxillary implant osteotomies in an attempt to obtain primary stability can easily overwhelm the compliance of the housing bone. Threads at the coronal aspect of the implant body compress and fracture the alveolus as the implant reaches final depth. This can be avoided by placing implants slowly and allowing time for ridge expansion during placement. Reverse cutting chambers present in some implant systems can also be employed in these situations as bone is cut when the implant is torqued counterclockwise. This in-and-out pattern allows manual placement to the desired depth with an appropriate insertional torque. In cases where cortical bone quality is brittle but underpreparation of the osteotomy is still desired, the author will frequently underprepare the overall width but relieve only the crestal cortical bone using a profile drill. This maximizes compression of the softer medullary bone throughout most of the implant body while avoiding fracture of the crestal cortical bone. Lastly, simultaneous pressure applied along the facial alveolar ridge during implant placement may decrease the incidence and severity of greenstick fractures. In all cases, implants torque should not exceed manufacturer recommendations.

Multiunit abutments are placed and torqued to manufacturer recommendations; and soft tissue is reapproximated. Final excision of excess soft tissue is conducted at this time with care to maintain a thick band of keratinized tissue surrounding each implant. Tissue is often excised from the palatal flap. A distal wedge is often removed from the tuberosity to facilitate removal of excess tissue and closure. Soft tissue is reapproximated with resorbable suture using a combination of individual and running sutures, (**Figures 17 A, B**)

The patient is then turned over to the prosthodontic team for conversion (**Figures 17 C-E**).

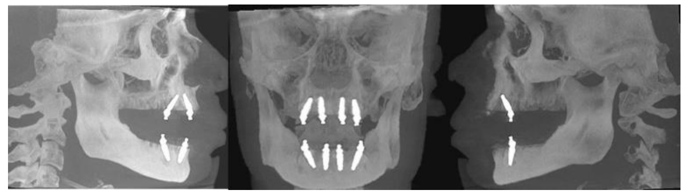
A)



B)

C)

D)



E)

Figure 17: ***A****, Final soft tissue closure with resorbable suture.* ***B****, Final soft tissue closure with resorbable suture.* ***C****, Day of surgery before and after clinical photos.* ***D****, Day of surgery before and after intraoral clinical photos.* ***E****, Postoperative radiographs.*

REFERENCES

1. Jensen OT, Adams MW. The maxillary M-4: a technical and biomechanical note for all-on-4 management of severe maxillary atrophy--report of 3 cases. *J Oral Maxillofac Surg Off J Am Assoc Oral Maxillofac Surg*. 2009;67(8):1739-1744. doi:10.1016/j.joms.2009.03.067.

2. Naert I, Quirynen M, van Steenberghe D, Darius P. A study of 589 consecutive implants supporting complete fixed prostheses. Part II: Prosthetic aspects. *J Prosthet Dent*. 1992;68(6):949-956.

3. Shackleton JL, Carr L, Slabbert JC, Becker PJ. Survival of fixed implant-supported prostheses related to cantilever lengths. *J Prosthet Dent*. 1994;71(1):23-26.

4. ten Bruggenkate CM, Oosterbeek HS, Krekeler G, Asikainen PJ. The placement of angled implants in the edentulous maxillae for the use of overdentures. *J Prosthet Dent*. 1991;66(6):807-809.

5. ten Bruggenkate CM, Sutter F, Oosterbeek HS, Schroeder A. Indications for angled implants. *J Prosthet Dent*. 1992;67(1):85-93.

6. Celletti R, Pameijer CH, Bracchetti G, Donath K, Persichetti G, Visani I. Histologic evaluation of osseointegrated implants restored in nonaxial functional occlusion with preangled abutments. *Int J Periodontics Restorative Dent*. 1995;15(6):562-573.

7. Brånemark PI, Svensson B, van Steenberghe D. Ten-year survival rates of fixed prostheses on four or six implants ad modum Brånemark in full edentulism. *Clin Oral Implants Res*. 1995;6(4):227-231.

8. Mattsson T, Köndell PA, Gynther GW, Fredholm U, Bolin A. Implant treatment without bone grafting in severely resorbed edentulous maxillae. *J Oral Maxillofac Surg Off J Am Assoc Oral Maxillofac Surg*. 1999;57(3):281-287.

9. Krekmanov L. Placement of posterior mandibular and maxillary implants in patients with severe bone deficiency: a clinical report of procedure. *Int J Oral Maxillofac Implants*. 2000;15(5):722-730.

10. 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(3):405-414.

11. 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(1):39-49. doi:10.1111/j.1708-8208.2001.tb00127.x.

12. Deporter DA, Watson PA, Pilliar RM, Howley TP, Winslow J. A histological evaluation of a functional endosseous, porous-surfaced, titanium alloy dental implant system in the dog. *J Dent Res*. 1988;67(9):1190-1195. doi:10.1177/00220345880670090801.

13. Sennerby L, Ericson LE, Thomsen P, Lekholm U, Astrand P. Structure of the bone-titanium interface in retrieved clinical oral implants. *Clin Oral Implants Res*. 1991;2(3):103-111.

14. van Blitterswijk CA, Bakker D, Hesseling SC, Koerten HK. Reactions of cells at implant surfaces. *Biomaterials*. 1991;12(2):187-193.

15. Wennerberg A. Implant design and surface factors. *Int J Prosthodont*. 2003;16 Suppl:45-47; discussion 47-51.

16. Albrektsson T, Wennerberg A. Oral implant surfaces: Part 1--review focusing on topographic and chemical properties of different surfaces and in vivo responses to them. *Int J Prosthodont*. 2004;17(5):536-543.

17. Cochran DL, Buser D, ten Bruggenkate CM, et. al. The use of reduced healing times on ITI implants with a sandblasted and acid-etched (SLA) surface: early results from clinical trials on ITI SLA implants. *Clin Oral Implants Res*. 2002;13(2):144-153.

18. Bornstein MM, Schmid B, Belser UC, Lussi A, Buser D. Early loading of non-submerged titanium implants with a sandblasted and acid-etched surface. 5-year results of a prospective study in partially edentulous patients. *Clin Oral Implants Res*. 2005;16(6):631-638. doi:10.1111/j.1600-0501.2005.01209.x.

19. Cameron HU, Pilliar RM, MacNab I. The effect of movement on the bonding of porous metal to bone. *J Biomed Mater Res*. 1973;7(4):301-311. doi:10.1002/jbm.820070404.

20. Brunski JB. Implants. Biomaterials and biomechanics. *CDA J*. 1988;16(1):66-77.

21. Schnitman PA, Wohrle PS, Rubenstein JE. Immediate fixed interim prostheses supported by two-stage threaded implants: methodology and results. *J Oral Implantol*. 1990;16(2):96-105.

22. Schnitman PA, Wöhrle PS, Rubenstein JE, DaSilva JD, Wang NH. Ten-year results for Brånemark implants immediately loaded with fixed prostheses at implant placement. *Int J Oral Maxillofac Implants*. 1997;12(4):495-503.

23. Balshi TJ, Wolfinger GJ. Immediate loading of Brånemark implants in edentulous mandibles: a preliminary report. *Implant Dent*. 1997;6(2):83-88.

24. Maló P, Rangert B, Nobre M. "All-on-Four" immediate-function concept with Brånemark System implants for completely edentulous mandibles: a retrospective clinical study. *Clin Implant Dent Relat Res*. 2003;5 Suppl 1:2-9.

25. Maló P, Rangert B, Nobre M. All-on-4 Immediate-Function Concept with Brånemark System® Implants for Completely Edentulous Maxillae: A 1-Year Retrospective Clinical Study. *Clin Implant Dent Relat Res*. 7(s1):s88-s94. doi:10.1111/j.1708-8208.2005.tb00080.x.

26. Maló P, de Araújo Nobre M, Lopes A, Francischone C, Rigolizzo M. "All-on-4" immediate-function concept for completely edentulous maxillae: a clinical report on the medium (3 years) and long-term (5 years) outcomes. *Clin Implant Dent Relat Res*. 2012;14 Suppl 1:e139-150. doi:10.1111/j.1708-8208.2011.00395.x.

27. Chrcanovic BR, Albrektsson T, Wennerberg A. Tilted versus axially placed dental implants: A meta-analysis. *J Dent*. 2015;43(2):149-170. doi:10.1016/j.jdent.2014.09.002.

28. Menini M, Signori A, Tealdo T, et. al. Tilted implants in the immediate loading rehabilitation of the maxilla: a systematic review. *J Dent Res*. 2012;91(9):821-827. doi:10.1177/0022034512455802.

29. Ata-Ali J, Peñarrocha-Oltra D, Candel-Marti E, Peñarrocha-Diago M. Oral rehabilitation with tilted dental implants: a metaanalysis. *Med Oral Patol Oral Cirugia Bucal*. 2012;17(4):e582-587.

30. Hopp M, de Araújo Nobre M, Maló P. Comparison of marginal bone loss and implant success between axial and tilted implants in maxillary All-on-4 treatment concept rehabilitations after 5 years of follow-up. *Clin Implant Dent Relat Res*. 2017;19(5):849-859. doi:10.1111/cid.12526.

31. Cawood JI, Howell RA. A classification of the edentulous jaws. *Int J Oral Maxillofac Surg*. 1988;17(4):232-236.

32. Tallgren A. The continuing reduction of the residual alveolar ridges in complete denture wearers: a mixed-longitudinal study covering 25 years. *J Prosthet Dent*. 1972;27(2):120-132.

33. Jensen OT, Ringeman JL, Adams MW, Gregory N. Reduced Arch Length as a Factor for 4-Implant Immediate Function in the Maxilla: A Technical Note and Report of 39 Patients Followed for 5 Years. *J Oral Maxillofac Surg*. 2016;74(12):2379-2384. doi:10.1016/j.joms.2016.08.002.

34. Jensen OT, Adams MW, Butura C, Galindo DF. Maxillary V-4: Four implant treatment for maxillary atrophy with dental implants fixed apically at the vomer-nasal crest, lateral pyriform rim, and zygoma for immediate function. Report on 44 patients followed from 1 to 3 years. *J Prosthet Dent*. 2015;114(6):810-817. doi:10.1016/j.prosdent.2014.11.018.

35. Jensen OT, Cottam JR, Ringeman JL, Graves S, Beatty L, Adams MW. Angled dental implant placement into the vomer/nasal crest of atrophic maxillae for All-on-Four immediate function: a 2-year clinical study of 100 consecutive patients. *Int J Oral Maxillofac Implants*. 2014;29(1):e30-35. doi:10.11607/jomi.te39.

36. Rosén A, Gynther G. Implant treatment without bone grafting in edentulous severely resorbed maxillas: a long-term follow-up study. *J Oral Maxillofac Surg Off J Am Assoc Oral Maxillofac Surg*. 2007;65(5):1010-1016. doi:10.1016/j.joms.2006.11.023.

37. Peñarrocha M, Carrillo C, Boronat A, Balaguer J, Peñarrocha M. Palatal positioning of implants in severely resorbed edentulous maxillae. *Int J Oral Maxillofac Implants*. 2009;24(3):527-533.

38. Peñarrocha-Oltra D, Candel-Martí E, Peñarrocha-Diago M, Martínez-González JM, Aragoneses JM, Peñarrocha-Diago M. Palatal positioning of implants in severely atrophic edentulous maxillae: five-year cross-sectional retrospective follow-up study. *Int J Oral Maxillofac Implants*. 2013;28(4):1140-1146. doi:10.11607/jomi.3001.

39. Peñarrocha M, Carrillo C, Boronat A, Peñarrocha M. Maximum use of the anterior maxillary buttress in severe maxillary atrophy with tilted, palatally positioned implants: a preliminary study. *Int J Oral Maxillofac Implants*. 2010;25(4):813-820.

40. Albrektsson T, Zarb G, Worthington P, Eriksson AR. The long-term efficacy of currently used dental implants: a review and proposed criteria of success. *Int J Oral Maxillofac Implants*. 1986;1(1):11-25.

41. Araújo MG, Wennström JL, Lindhe J. Modeling of the buccal and lingual bone walls of fresh extraction sites following implant installation. *Clin Oral Implants Res*. 2006;17(6):606-614. doi:10.1111/j.1600-0501.2006.01315.x.

42. Brånemark PI, Adell R, Albrektsson T, Lekholm U, Lindström J, Rockler B. An experimental and clinical study of osseointegrated implants penetrating the nasal cavity and maxillary sinus. *J Oral Maxillofac Surg Off J Am Assoc Oral Maxillofac Surg*. 1984;42(8):497-505.

43. Elhamruni LMM, Marzook HAM, Ahmed WMS, Abdul-Rahman M. Experimental study on penetration of dental implants into the maxillary sinus at different depths. *Oral Maxillofac Surg*. 2016;20(3):281-287. doi:10.1007/s10006-016-0568-z.

44. Jung J-H, Choi B-H, Jeong S-M, Li J, Lee S-H, Lee H-J. A retrospective study of the effects on sinus complications of exposing dental implants to the maxillary sinus cavity. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*. 2007;103(5):623-625. doi:10.1016/j.tripleo.2006.09.024.

45. Oh E, Kraut RA. Effect of sinus membrane perforation on dental implant integration: a retrospective study on 128 patients. *Implant Dent*. 2011;20(1):13-19. doi:10.1097/ID.0b013e3182061a73.

46. Jensen OT, Adams MW, Cottam JR, Parel SM, Phillips WR. The All-on-4 shelf: maxilla. *J Oral Maxillofac Surg Off J Am Assoc Oral Maxillofac Surg*. 2010;68(10):2520-2527. doi:10.1016/j.joms.2010.05.082.

47. Bedrossian E, Sullivan RM, Fortin Y, Malo P, Indresano T. Fixed-prosthetic implant restoration of the edentulous maxilla: a systematic pretreatment evaluation method. *J Oral Maxillofac Surg Off J Am Assoc Oral Maxillofac Surg*. 2008;66(1):112-122. doi:10.1016/j.joms.2007.06.687.

48. Jensen OT. Complete arch site classification for all-on-4 immediate function. *J Prosthet Dent*. 2014;112(4):741-751.e2. doi:10.1016/j.prosdent.2013.12.023.

49. Jensen OT, Adams MW, Smith E. Paranasal bone: the prime factor affecting the decision to use transsinus vs zygomatic implants for biomechanical support for immediate function in maxillary dental implant reconstruction. *Int J Oral Maxillofac Implants*. 2014;29(1):e130-138. doi:10.11607/jomi.te52.

50. Graves S, Mahler BA, Javid B, Armellini D, Jensen OT. Maxillary all-on-four therapy using angled implants: a 16-month clinical study of 1110 implants in 276 jaws. *Dent Clin North Am*. 2011;55(4):779-794. doi:10.1016/j.cden.2011.07.007.

51. Jensen OT, Adams MW. Anterior sinus grafts for angled implant placement for severe maxillary atrophy as an alternative to zygomatic implants for full arch fixed restoration: technique and report of 5 cases. *J Oral Maxillofac Surg Off J Am Assoc Oral Maxillofac Surg*. 2014;72(7):1268-1280. doi:10.1016/j.joms.2014.02.006.

52. 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 Off J Am Assoc Oral Maxillofac Surg*. 2012;70(1):141-148. doi:10.1016/j.joms.2011.03.045.

53. Borris TJ, Weber CR. Intraoperative nasal transillumination for maxillary sinus augmentation procedures: a technical note. *Int J Oral Maxillofac Implants*. 1998;13(4):569-570.