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

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BACKGROUND

A full-arch prosthesis supported by four, tilted implants at the cornerstones of the mandibular arch is a common rehabilitation option for the edentulous or terminal dentition. Frequently called All-on-Four®, this treatment is the result of constant debate over ideal implant number, tilted versus axial implants, and grafting versus graftless treatment modalities.

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.

To meet functional patient needs, research suggested that optimal restoration of a dental arch have at least 20 occluding teeth.[1,2] For years, biomechanical dogma regarding implant placement centered on the belief that lateral forces were detrimental. Nonaxial implant placement was believed to increase implant failure and peri-implant bone resorption. Early protocols recommended axial implants be confined to the interforaminal region due to anatomic limitations imposed by the inferior alveolar nerve and posterior bone height. This required cantilevering posterior teeth in the region of the mouth with highest biomechanical stress. There is direct association with cantilever length and implant failure, particularly with distal cantilevers greater than 15 mm.[3,4] Thus, many surgical solutions have been proposed to strengthen prosthetic support by increasing interimplant spread. These include nerve lateralization, bone augmentation, and tiled implants.

Mandibular All-on-Four® is a common treatment modality used by clinicians all over the world for immediate, full-arch rehabilitation. This technique evolved as a graftless solution which sought to reduce treatment time and avoid complications associated with bone grafting and nerve lateralization.

Tilting posterior implants over the mental foramen increases the AP spread and decreases the length of the cantilever. Studies emerged supporting the use of tilted implants as a solution.[5,6] Long-term studies are now available that support tilting implants and the All-on-Four® treatment modality. Advantages of tilting implants include:

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[7]

ALL-ON-FOUR® HISTORY

In 1991 and 1992, Bruggenkate published reports of angled implant placement in the posterior mandible used to support overdentures.[8,9] 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.[10]

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 four 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.[11] This publication was the first to demonstrate equal success with an implant foundation consisting of only four implants.

In 1997, Krekmanov and Rangert reported initial success with placement of mandibular implants angled posteriorly over the mental foramen to decrease cantilever length.[12] A follow up study was published in 2000, in which 36 tilted mandibular implants were placed in 22 patients.[5] The patients were followed for at least 40 months and demonstrated a 100% success rate of mandibular implants. The tilting of the implants over the mental foramen allowed for an average increased AP spread by 6.5 mm.

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 six to eight 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 osseointegration. 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.[13–19]

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.[20,21] This finding was perhaps best reported by Schnitman et. al. in 1990.[22] 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.[23] 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 four 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.[6,24,25] In 2003, Malo et. al. reported his success with immediately loading mandibular restorations utilizing four implants, two posterior angled and two anterior axially placed implants.[6] The idea of Malo’s protocol was to place four implants at the cornerstones of the mandibular arch to support the prosthesis. He performed immediate full-arch rehabilitation in 44 patients with 176 implants. Twenty-Four of the first 30 patients had two “rescue implants'' placed that remained buried and were only used in the final prosthesis; this was termed the development group. Due to the success of the first 30 patients, the remaining 14 patients had no rescue implants placed. The anterior implants were placed axially following the mandibular anatomy and posterior implants were placed just anterior to the mental foramen and angled posteriorly 30 degrees to the occlusal plane. All implants were placed with an insertional torque of over 40 Ncm. A metal-reinforced, acrylic prosthesis was placed at the time of surgery. Final restorations were placed four to five months after surgery in the development group and the remaining patients maintained the provisional restoration for the duration of the study. At one year, both groups demonstrated a 100% prostheses survival rate and a 96.7% and 98.2% survival rate in the development group and routine group, respectively. This confirmed the feasibility and success of immediately rehabilitating the mandibular arch with angled and axially placed implants. Medium and long-term follow-up studies published by Maló corroborated original findings with similar levels of success.[26]

MANDIBULAR ALL-ON-FOUR® SUCCESS

Ata-Ali et. al performed a meta-analysis of axial and tilted implants in 2012.[27] The analysis included 13 publications with implants placed in both maxillary and mandibular arches. They included seven retrospective studies and six prospective studies. They reported no statistical difference in success rates and marginal bone loss in axially versus tilted implants.

In 2015, Chrcanovic et. al. performed a meta-analysis comparing the failure rate and marginal bone loss in tilted versus axially placed dental implants. Forty-Four articles were included that accounted for the placement of 5,732 axial implants and 5,027 tilted implants. There was no statistical significance difference between failure rates and bone loss between the two groups.[28]

A limitation of these meta-analyses is the large number of confounding variables in the included studies including: surgical techniques, surgical experience, implant designs, prosthetic designs, and medical comorbidities of patients.

In 2011, Malo followed up his original publication evaluating the long-term success of restoring mandibular arches in accordance with the All-on-Four® protocol. The longitudinal study evaluated 245 patients treated from May 1999 to November 2004 with an immediately-loaded mandibular prosthesis. The surgeries were all performed by the same two surgeons and followed the same surgical protocol. A total of 21 of the 980 implants failed giving an implant success rate of 98.1% at five years and 93.8% at 10 years.[29] In 2018, Malo continued to evaluate success and reported that at 18 years the All-on-Four® treatment protocol had a 91.9% implant success rate and a 99.6% prosthetic survival rate. The reported levels of marginal bone loss were 1.52 mm and 2.32 mm at 10 and 15 years, which is in accordance with other published, implant studies. [30]

The biomechanical advantages of the All-on-Four® treatment has also been demonstrated. In 2011, Fazi et. al. performed a finite element analysis on different implant configurations for full-arch rehabilitation. They reported that four or five vertically placed implants showed a similar stress response in bone. This was in stark contrast to the biomechanical stability of only three implants. They also reported that when distal implants were tilted 30 degrees posteriorly, a significant decrease in stress to the bone, implant, and prosthesis existed.[31]

In 2018, Ozan demonstrated the biomechanical advantage of angled distal implants used to shorten cantilevers. A three-dimensional finite element analysis was used to evaluate the stress placed on the implants, abutments, framework and prosthetic screws. Four different implant arrangements were used: four axially placed implants, two axially placed implants with distal implants angled 17 degrees, two axially placed implants with distal implants angled 30 degrees, two axially placed implants with distal implants angled 45 degrees. The results demonstrated that angling implants 30 degrees and 45 degrees toward the distal decreased stress of the system and produced a better distribution of the stress.[32]

MANDIBULAR AGE-RELATED CHANGES

As patients lose teeth, the forces applied to the mandible change. Over time the mandible adapts to these alternative forces and the bony architecture changes accordingly. These changes progress over time and multiple studies have demonstrated how edentulism affects the mandible.

One of the most comprehensive studies of edentulous mandibles occurred in 1988 when Cawood and Howell evaluated 300 dried cadaveric mandibles and classified them into six classes based on the extent of bony resorption. A dentate mandible was specified as class I. Class II mandibles were defined as mandibles immediately post-extraction with adequate alveolar height and width. Class III mandibles represented a well-healed alveolar ridge with adequate vertical and horizontal bone. Class IV mandibular arches demonstrated severe horizontal resorption but retained an adequate alveolar height. In a class V mandible there was an inadequate height and width but the basal bone remained stable. Finally, a class VI mandible demonstrated changes that affected the basal bone as well.[33]

Pietrokovski et. al. evaluated 99 dried, edentulous mandibles at the molar, premolar, and incisor sites and evaluated changes in the residual alveolar ridge. They reported that resorption occurred in a centrifugal and apical pattern which forced the residual mandibular arch to become wider and shorter with time. In the samples, they noted that 75% mandibles had a ridge width less than 2 mm at the incisors.[34] This so-called "knife-edge" is important to the surgeon as bone reduction is required to reduce this edge and create space suitable for implant placement.

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 observed the greatest dimensional changes occurred within the first year of edentulism. He also observed that vertical bone of the anterior mandible was lost at a rate four-times greater than the maxilla after a seven-year observation period.[35] (**Figure 1**)

A)

B)

***Figure 1**. **A**, Pseudo Class III maxillomandibular relationship resultant of progressive, predictable patterns of mandibular resorption. **B**, The atrophic mandible. Residual basal bone present with close proximity of mental foramina and alveolar ridge.*

INFERIOR ALVEOLAR NERVE ANATOMY

Iatrogenic damage to the inferior alveolar nerve (IAN) during implant placement may be direct or indirect and has been reported to cause anesthesia, paresthesia and dysesthesia.[36,37] An anatomic review with surgical implications is warranted.

The IAN enters the mandible at the mandibular foramen on the medial aspect of the mandibular ramus. The vertical intraboney course follows a slight curve with the lowest point near the first molar before anteriorly ascending near the foramen.[38] The horizontal pathway is medial to lateral with the neurovascular bundle positioned in the middle of the mandible at the first molar position before coursing laterally toward the mental foramen.[39] In the region of the first molar/premolars the nerve splits into the mental nerve and the incisive nerve. The mental nerve exits the mental foramen; the incisive nerve continues through the incisive canal innervating the mandibular anterior teeth.[40] Vertical and horizontal variability on the location of the mental foramen is prevalent and bears clinical relevance as this anatomic boundary is intimately associated with maximizing interimplant distance. The mental foramen is most commonly located near the apex of the second mandibular premolar or between the premolar apices, although anterior and posterior extremes of canine and molar positions have been reported as well.[39] Fishel et. al. evaluated 936 periapical radiographs of the mental foramen and reported that vertically the foramen is located apical to the apex of the first bicuspid root in 24.5%, at the apex 13.9% and superior to the apex 61.6% of the time.[41] Near the foramen, the nerve bifurcates or trifurcates innervating the skin of the chin, lower lip, and gingiva. Most commonly, one foramen is reported for each nerve. However, bifid and trifid foramina are rare anatomic variants hypothesized to be a developmental anomaly resulting from a failure of fusion of the branches of the mental nerves. In 2015, Motamedi et. al. evaluated 5,000 consecutive panoramic images and noted an incidence of 1.2%. This is consistent with a 2018 study by Sonneveld that evaluated 2,130 CT scans and noted an incidence of 1.31%.[42, 43]

The anterior mental loop of the inferior alveolar canal has been a topic of debate with large size discrepancies and prevalences reported throughout the literature. A 2020 systematic review included 32 articles and 2,503 patients and reported an average radiographic loop length of 2.76 mm (range 0.3-19 mm). In purview of clinical significance, this wide range prompted the suggestion that radiographic averages be substituted with patient-tailored imaging. All available imaging should be considered prior to implant surgery.[44] In contrast to radiographic studies, cadaveric studies are suggestive of a much smaller size and a decreased prevalence of the anterior loop and imply it is less of a clinical factor. An *in vivo* study by Rosenquist evaluated the mental nerve in 58 patients who were undergoing nerve lateralization. No anterior loop was reported in 43 patients. Thirteen patients had a 0.5 mm anterior loop and only two patients had a 1 mm anterior loop.[45] This was supported in 2010 by Benninger et. al. who evaluated 30 cadaveric mandibles, in which 87% of these cases showed no anterior loop. The loop was less than 1 mm in the remaining 13% of cases.[36]

One of the terminal branches of the IAN, the mandibular incisive nerve, provides sensation to the mandibular anterior teeth and courses through the mandible anterior to the mental foramen. In 2004, Jacobs et. al. evaluated 545 consecutive panoramic images and was only able to visualize the mandibular incisive canal 15% of the time.[46] This is in contrast to evaluation by cone beam CT in which the canal was visible in 93% of cases.[47] Mraiwa et. al. evaluated 50 cadaveric mandibles and reported the canal was macroscopically visible in 96% of the specimens with an average diameter of 1.8 mm. The canal was an average of 9.7 mm from the inferior border and sloped slightly inferior as it extended to the dental midline.[40, 37] The incisive canal is clearly a consistent anatomical structure but questions remain on the clinical relevance to implant surgery. (**Figure 2**)

Figure 2. *Branches of the mental nerve as they exit the mental foramen.*

In 2013, Kutuk et. al. evaluated 50 patients with dental implants placed in the interforaminal zone of the mandible. Of the 50 patients, 10 reported complaints of neuropathic pain. CT imaging revealed each patient had implant invading the incisive nerve. This demonstrates that the incisive nerve is a structure of surgical consideration when placing dental implants anterior to the mental foramen.[48]

In 2006, Abarca sent a post-op questionnaire to 65 patients who underwent full-arch implant rehabilitation with interforaminal implants. They reported temporary neurosensory disturbances as high as 33%.[49] Persistent neurosensory disturbances associated with the All-on-Four® protocol have been reported as low as 0.25% by Jensen. Francetti et. al. reported one temporary neurosensory disturbance in a review of 62 of patients restored with the All-on-Four® protocol.[50, 51]

The literature supports that the anterior loop of the mental nerve should always be evaluated radiographically. The clinical significance of this finding is controversial. Historic measurements and studies have effectively protected patients from neurosensory disturbances and cannot be undervalued. The incisive canal is the distal most extension of the mandibular nerve and can be radiographically and clinically assessed when implant placement in the interformainal region is considered. Neurosensory disturbances reported with violation of this structure are a risk that do not appear to be correlated with the high successes reported with traditional All-on-Four® surgery. More studies are needed to guide patients and clinicians.

MANDIBULAR ARCH CLASSIFICATION

Preoperative radiographic assessment may show adequate bone volume for implant placement. Qualitative differences in the amount of cortical/cancellous bone, degree of mineralization, and hollow/porous medullary spaces may make primary implant fixation difficult to achieve.

Sufficient mechanical implant fixation is often derived from apical and crestal cortical bone which may not be apparent until alveolar reduction is performed. Jensen proposed an All-on-Four®, immediate-loading, site classification that takes into account the presence of residual, load-bearing bone for implant fixation. While traditional classification schemes have focused on preoperative bone availability, this classification system is applied intraoperatively after alveolar reduction with the goal of achieving the primary, mechanical fixation necessary for immediate function. 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.[52]

Alveolar reduction is prosthetically necessary and results in a level platform or shelf. The Mandibular All-on-Four® Shelf has many benefits first published by Jensen.[53]

1. Establishes prosthetic restorative space
    a. A minimum of 15 mm is needed
2. Establishes a level alveolar plane and uniform implant levels

a. Reestablishment of an alveolar plane parallel with the interpupillary line and Frankfort horizontal is created

3. Establishes alveolar width for implant diameter selection
4. Bone reduction makes basal bone accessible for implant fixation
5. Helps to establish arch form, implant distribution, and AP spread
6. Identifies optimal implant sites
7. Identifies secondary implant sites
8. Exposes lingual plate width and lingual concavities
9. Facilitates posterior implant placement with respect to the nerve
10. Provides bone stock for secondary bone grafting

Class A

Class A mandibles demonstrate sufficient vertical bone above the IAN for axial anterior and posterior implant placement. An IAN with a pronounced inferior deflection/position is necessary. The four implants may be placed 20 mm or more apart with an interarch implant span greater than 60 mm. The interim and final prostheses often have no distal cantilever. Only 3% of mandibles were reported to meet this criteria. (**Figure 3**)

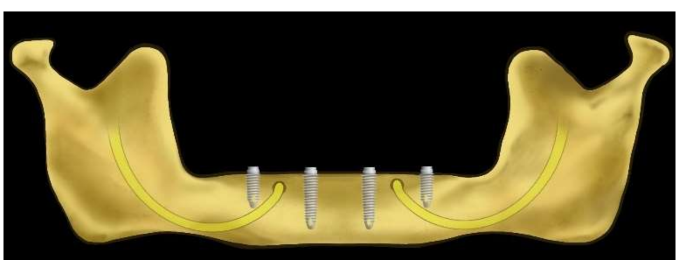
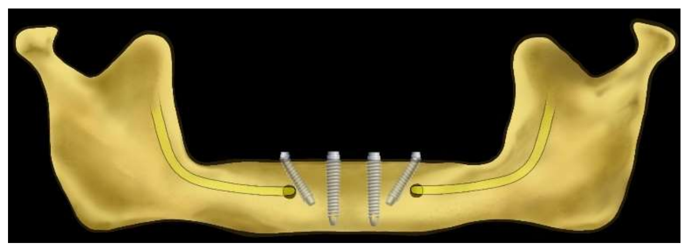


Figure 3. *Schematic representation of Jensen Class A mandible.*

Class B

Class B mandibles possess several millimeters of bone above the inferior alveolar canal which requires the posterior implants be angled distally over the mental foramen with the restorative platform near the second premolar site. The anterior implants are placed axially near the sites of the lateral incisors and canines. To increase the AP spread, the posterior implants may also be angled buccal to lingual in a transalveolar direction which allows for the implant to be posterior to the mental foramen at the first molar site. The implants are spaced 15 mm apart and the interimplant span is between 40-45 mm. The distal cantilever is usually limited to less than 10 mm. 23% of mandibles are class B making it the second most common. (**Figure 4**)



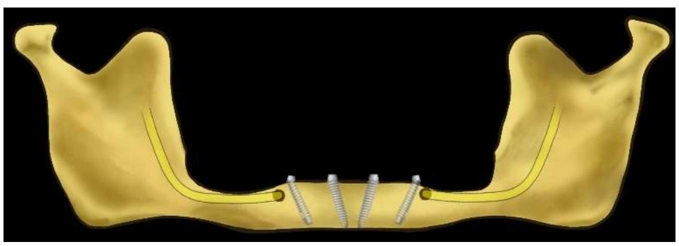
A)

B)

Figure 4. ***A****, Schematic representation of Jensen Class B mandible.* ***B****, Schematic representation of Jensen Class B mandible with posterior implant entry points medial to the mandibular nerve.*

Class C

Class C mandibles have almost no bone superior to the mental foramen. The distal implants are angled posterior 30-45 degrees, and the platform emerges at approximately the first premolar site. Anterior implants are also angled, creating the “V4” formation when viewed on an orthopantomogram. Angling the anterior implants allows use of longer implants and prevents the convergence of implants, which could lead to a mandibular fracture. The AP spread is reduced to 10-12 mm and the interimplant distance is 30-40 mm. The distal cantilever is 10 mm and will only restore a partial first molar. This is the most common class in which 25% of mandibles were reported. (**Figure 5**)



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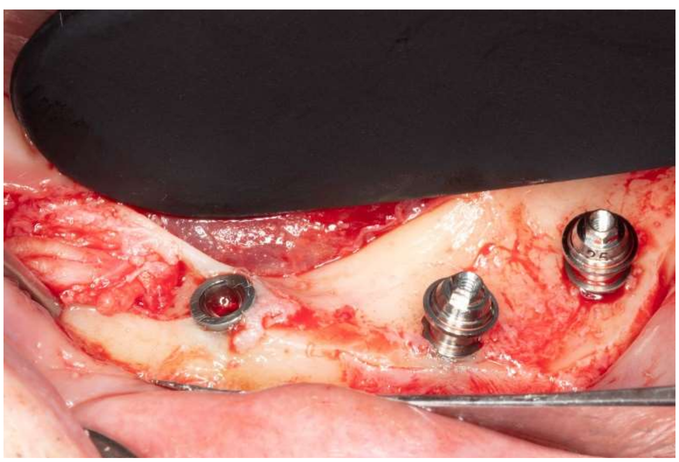
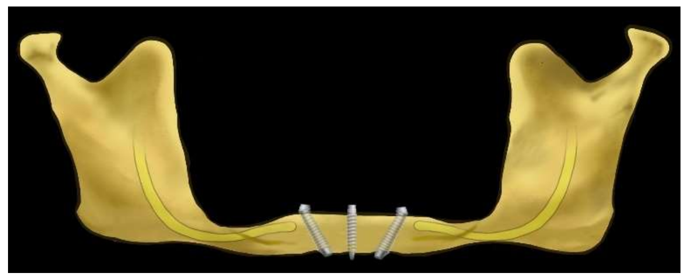


B)

***Figure 5. A**, Schematic representation of Jensen Class C mandible. **B**, Class C mandible with nerve lateralization/distalization to increase inter-implant spread.*

Class D

Class D mandibles are highly atrophic with less than 10 mm of vertical height. Only three implants may be considered to restore the arch and maximize the AP spread. Three implants are considered because, biomechanically, the anterior implants would be so close they would function as a single implant. Even with three implants the AP spread is usually between 8-12 mm with an interimplant distance of 25-35 mm. The cantilever is generally 10 mm and restored with a shortened dental arch. This is the least common variant with only 2% of mandibles reported as class D.[52] (**Figure 6**)



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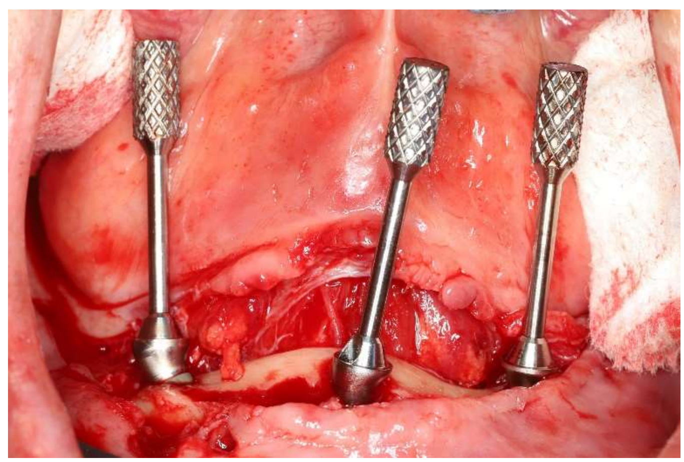

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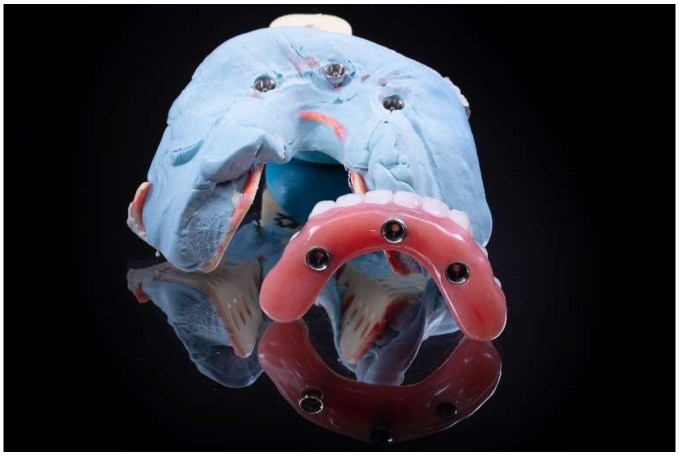


C)

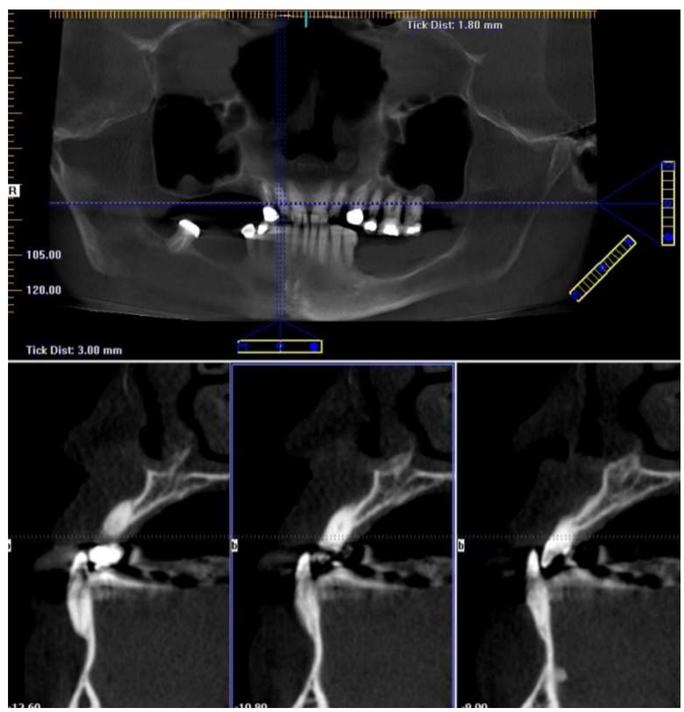
***Figure 6. A**, Schematic representation of Jensen Class D mandible. **B**, All-on-3 implant placement on a Class D mandible with severe bone atrophy. **C**, All-on-3 provisional, acrylic restoration.*

THE HOURGLASS MANDIBLE

Mandibles with severe constrictions are rare anatomic variants with an incidence of 3.89%.[54] Constrictions are commonly found at the junction of the alveolus and basal bone and thought to be a developmental abnormality. They present significant challenges to the operating clinician as bone availability may be minimal making implant fixation and immediate function uniquely challenging.

Mandibles may have facial constrictions, lingual constrictions, or both facial and lingual constrictions resulting in a true "hourglass" silhouette when viewed in a sagittal plane. Width and height of the constrictions are variable. Some maintain a trabecular component between facial and lingual cortical plates. In extreme cases, facial and lingual cortices fuse. (**Figure 7**)

A)

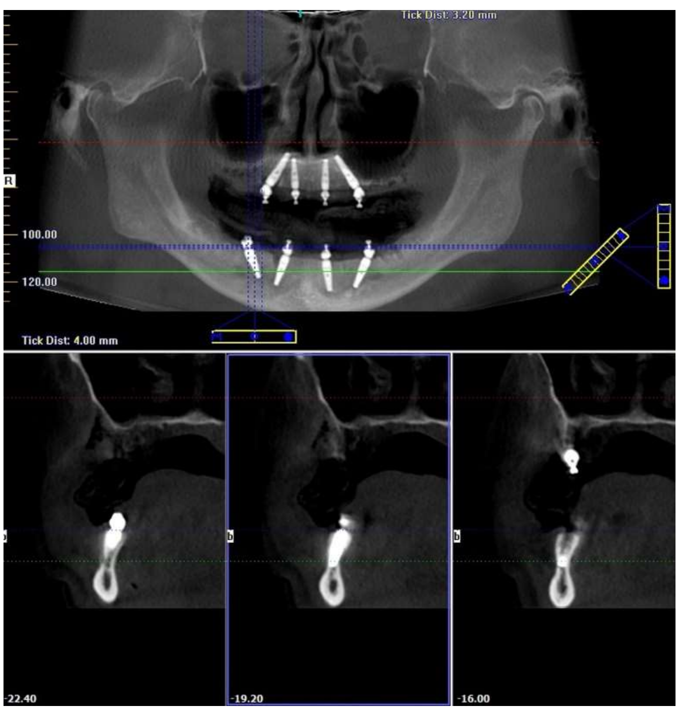


B)

***Figure 7. A**, Alveolar constriction with minimal trabecular bone. **B**, Severe hourglass constriction with complete fusion of facial and lingual cortical plates inferior to alveolar bone.*

Implant rehabilitation of this patient subset is controversial and highly dependent on patient-specific anatomy. Patients may benefit from a staged surgical approach where grafting is first used to rebuild supporting bone. Butura et. al. reported 10 cases where graftless All-on-Four® surgery was performed by using long, tilted implants and traversing through mandibular constrictions. Implant trajectories started in alveolar bone, left the mandibular body, and reentered the basal bone for apical stability.[54]

In all cases, the hourglass mandible may be considered a relative contraindication for All-on-Four® implant therapy. Blood supply is primarily derived from periosteum and compromised. Narrow diameter implants are required and thread exposure along aspects of the implants are likely. Early and late-stage bone loss are potential complications. Surgical handling properties of brittle, narrow bone make alveolar fracture possible during placement. (**Figure 8**)



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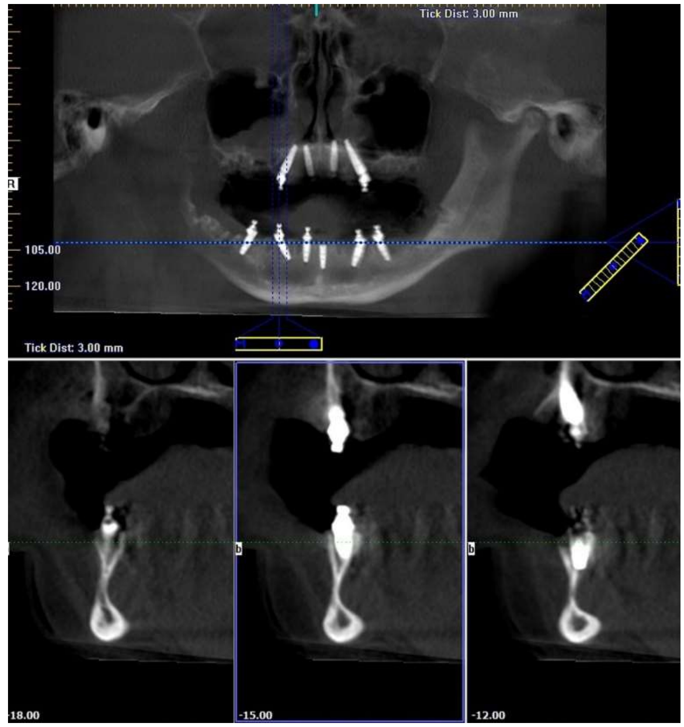


B)

***Figure 8. A**, Hourglass mandible treated with immediate function by the author. Alveolar constrictions were traversed and basal bone engaged for primary implant fixation. **B**, Hourglass mandible treated with immediate function by the author. The alveolar constrictions were avoided with shorter implants fixated above the point of greatest constriction.*

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 mandibular osteotomy which, in turn, directs functional implant positions and angulations.

The vertical position of the mandibular osteotomy after extractions and alveolar reduction is sometimes referred to as the "All-on-Four® Shelf".[53]

For zirconia, 12 mm or greater of vertical space above the level of the soft tissue is needed to meet minimum prosthetic space requirements.[55] Any less than this vertical requirement will compromise the strength of 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.

Inadequate mandibular alveolar reduction can result in challenging esthetic outcomes, causing excessive display of mandibular teeth. If the acceptable vertical dimension of occlusion is exceeded, the patient's closest speaking space will be invaded, causing their teeth to contact during speech.[56] (**Figure 9**)

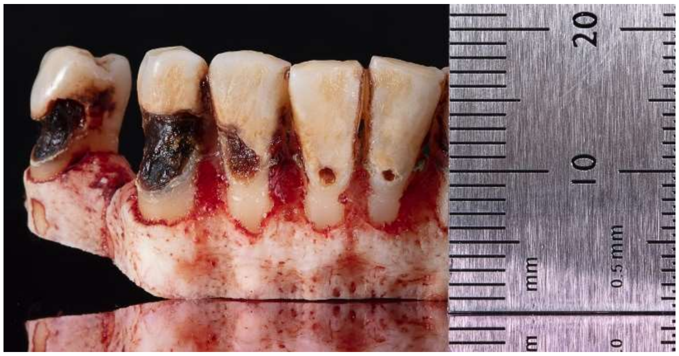


Figure 9. *Teeth and alveolar bone reduction. Supraeruption of this anterior mandibular segment required more than 15 mm of vertical space.*

RADIOGRAPHIC ASSESSMENT

An initial, cursory appreciation of bone volume and overall dental condition can easily be obtained with an orthopantomogram or panoramic reconstruction of a CBCT. For the terminal dentition, dental caries, periodontal disease, chronic periapical infection, and supraeruption/migration of dentoalveolar segments often result in an uneven, mutilated occlusal plane with questionable alveolar support.

Preliminary radiographic evaluation should be visualized at the vertical level of the proposed mandibular osteotomy. Often, this position places the future All-on-Four® Shelf in close proximity with the inferior alveolar nerve at the mental foramen and decreases 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 mandibular 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. 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 factors 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. Nerve positions, tori, hourglass mandibles/alveolar constrictions, and residual bone at this level are now more easily compared. (**Figure 10**)

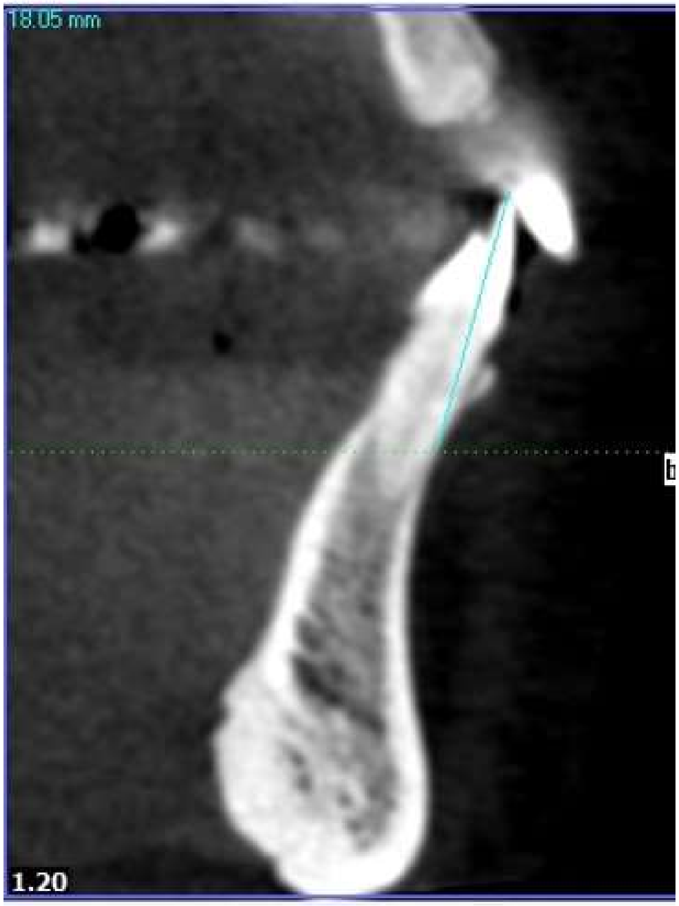


Figure 2 *Proposed vertical reduction as measured from the incisal edge of anterior lower incisor.*

Proposed positions of posterior implants are assessed. To avoid the anterior extent mental nerve, 30-45 degree posterior implants are planned. Half the diameter of the proposed implant plus a 2 mm historic "safe zone" is measured from the mental foramen. 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. Potential anterior implant sites are similarly evaluated with entry points at the lateral incisor regions. (**Figure 11**)

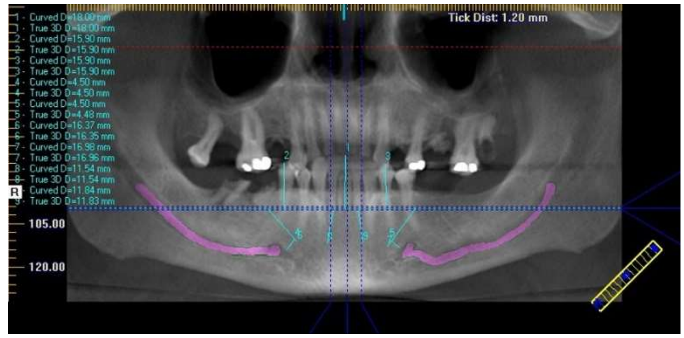
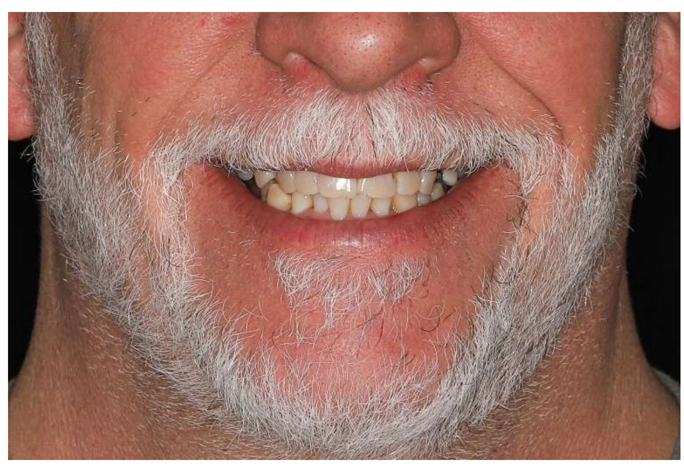


***Figure 11**. Proposed vertical level of the mandibular osteotomy as viewed on a reconstructed CBCT. IAN is highlighted in pink.*

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 or residual bone levels 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.

SURGICAL STEPS

There are numerous ways to perform mandibular All-on-Four® surgery. The following steps detail the sequence utilized by the author in private practice. (See Figures 10, 11; **Figure 12**)



A)

B)

C)

***Figure 12. A**, Preoperative smile. **B**, Intraoral preoperative smile. **C**, Intraoral preoperative occlusal view of terminal mandibular dentition and archform.*

Local anesthesia with epinephrine is infiltrated bilaterally in the mandibular vestibules. Bilateral IAN, long buccal, and retromylohyoid nerve blocks are performed.

In dentate patients, a sulcular incision is performed with a #15 blade with bilateral, distobuccal, posterior releasing incisions distal to the second molar positions. The incision design and location should be anticipatory of the final soft tissue position ensuring sufficient keratinzed tissue will be maintained facial and lingual to the final implant positions. A full-thickness mucoperiosteal flap is subsequently elevated. Bilateral mental foramina are dissected and exposed. Careful reflection of the periosteum and associated neurovascular bundle affords the benefit of direct visualization and the possibility of bone sounding of the anterior loop/wall of the canal in cases. Mental nerves are protected during the procedure. Additionally, exposure of the mental nerves serves as a visual aid to prevent inadvertent over-reduction. Direct visualization of the bundle is necessary to avoid iatrogenic injury during osteotomy preparation and implant placement. In patients with tenacious mentalis muscle attachments, superior fibers are sometimes incised and reflected judiciously allowing for reduction while avoiding lower lip ptosis. The incision design is slightly modified in edentulous patients. The incision remains crestal while judiciously splitting residual, keratinized tissue. Partial thickness incisions and blunt dissection to locate the neurovascular bundle is sometimes necessary when severe atrophy has resulted in a superior, crestal nerve position.

A caliper and sterile pencil are utilized to measure the proposed vertical reduction utilizing either the incisal edges of residual teeth or alveolar bone levels as reference points. These measurements are gleaned from the restorative treatment plan and take into account the underlying bone anatomy, potential supraeruption of teeth/alveolar segments, planned prosthetic changes in occlusal vertical dimension, as well as patient-specific mechanical/strength considerations. Usually, this measurement is 15-17 mm from the incisal edges of the central incisors. Bone coronal to this line is planned for removal and removed with a bur and irrigation to facilitate less traumatic dental extractions. Teeth are elevated and extracted with care to preserve the integrity of the remaining alveolar bone.

A lingual incision is performed along the alveolar crest to excise the interdental papillae and circumdental gingival fibers. This soft tissue is removed with a ronguer. A full-thickness lingual flap is then elevated with a periosteal elevator. Soft tissue is mobilized and elevated inferiorly to the level of the mylohyoid ridge and posterior to the second molars to allow adequate retraction and protection of vital structures during surgery. In cases of significant lingual undercuts, a molt elevator is sometimes helpful for subperiosteal dissection and visualization of boney anatomy.

A clear, slotted, surgical guide is placed. The palate, tuberosities, retromolar pads, and an interdental bite registration are used as stable references to ensure the appropriate vertical dimension of the final prosthetic is represented. The patient's mandible is guided in CR into the windowed/slotted surgical guide. The proposed alveolar reduction is marked with a sterile pencil. (**Figure 13**)

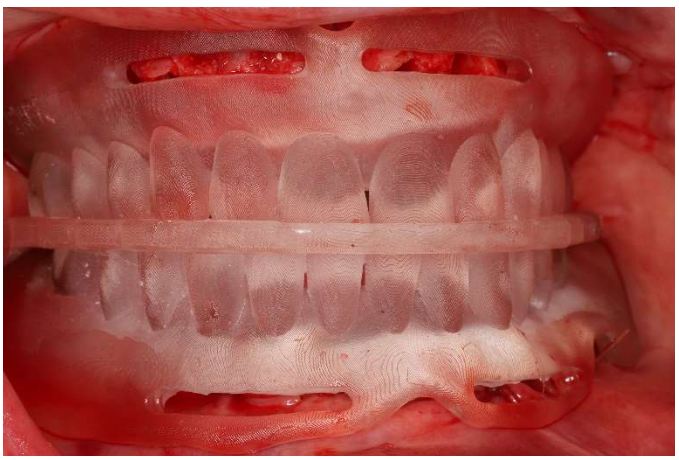


Figure 13. *Clear, slotted surgical guide in place. Slots allow for easy visualization of vertical space requirements.*

The All-on-Four® Shelf is created. An aggressive reduction bur, ronguer, reciprocating saw, or fissure bur is used to reduce the alveolus to the proposed vertical level. Tori, if present, are often included in the necessary reduction. If not, residual tori are removed/recontoured at this time. Alveolar reduction often increases shelf width allowing ample room for standard diameter implants. Anatomic variants exist where minor alveolar constrictions are present at the level of the osteotomy. The surgeon must then decide to further reduce a segment of the ridge to widen the platform or proceed with a smaller diameter implant.

Alveolar reduction is the first time the surgeon is afforded the opportunity to appreciate the 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. As the shelf brings the implant platforms in closer proximity to basal bone of the inferior cortex, these technical challenges can often be overcome with the use of longer implants.

Mandibular bone is generally categorized as D1/D2 in quality. However, with progressive vertical reduction, the shelf widens, sometimes exposing a large, hollow, and porous medullary space. A steady fulcrum as the bur is directed in an anteroposterior direction allows for cautious reduction of the facial/lingual cortical bone without accidental tunneling into the porous medullary spaces.

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 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 mandibular osteotomy.

1. The vertical dimension from the incisal edges of select teeth to the proposed osteotomy level

2. The vertical dimensions from the mental foramina, though often asymmetrical, 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

After alveolar reduction is verified, residual extraction sockets are curetted and cleaned of any remaining granulation tissue and debris. Facial and lingual 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 damage to the neurovascular bundle. The position of the IAN is the most common anatomic limitation of AP spread. Preoperative assessment of the inferior alveolar nerve canal with any anterior loop combined with direct visualization of the mental nerve during surgery are measures taken to avoid iatrogenic injury. 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.

Historic precautions regarding implant entry points are calculated by adding half the diameter of the implant to a 2 mm safe zone anterior to the mental foramen and angling the implant 30-45 degrees anteriorly. This often allows placement of the fixture in the center of the alveolar ridge. Bearing in mind that the mental nerve passes laterally as it exits the mandible, a medial implant entry-point may diminish the risk of damage to the IAN and even allow a more posterior entry point. This maximizes AP spread as the implant essentially parallels the nerve as it traverses anteriorly and achieves good mechanically stability in the thick lingual cortex of the mandibular shelf.[53,54]

Posterior implant trajectories may be centered on the residual ridge and angled anteriorly 30-45 degrees. Anterior entry points are at the lateral incisor/canine region and may be axial or with a slight angulation. Surgical steps consist of sequential twist drills with irrigation. Very dense bone may benefit from profiling the crestal aspect, overpreparation of the osteotomy length, bone tapping, and utilizing the reverse cutting chambers located on most implant systems during manual placement.

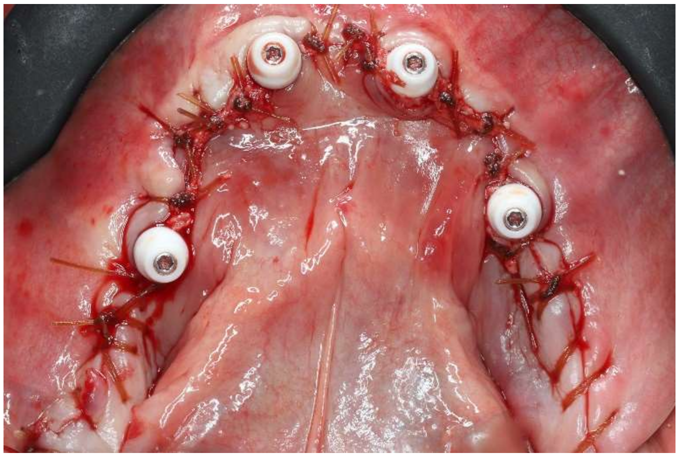
Special surgical considerations are necessary in patients with poor bone quality. Underpreparation and compression of hollow medullary spaces often results in low/no primary implant stability. In this setting, the surgeon has a few options to consider. If a prominent lingual plate is present, a longer implant can be directed into the inferior border of the mandible. The implant derives crestal and apical stability in dense cortical bone. Alternatively, the implant trajectory can pass in a transalveolar manner from buccal to lingual piercing the lingual cortical plate along the mylohyoid ridge.[50,57] (**Figure 14**)

Figure 14. *Dense lingual bone at the mylohyoid ridge is represented clearly by lack of translucency. It can be selectively exploited for apical implant fixation in appropriate candidates.*

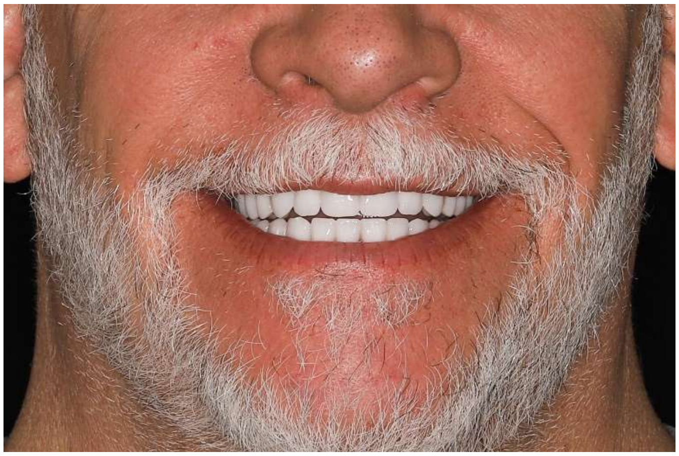
Primary insertion torque is important for immediate loading, but the composite torque value is of greater clinical significance. This is due to the cross-arch stabilization derived from the prosthesis and the secondary implant stability derived from the lateral surfaces of four *angled* implants in bone. Tilting implants is not only performed to avoid anatomic structures, it increases the overall retention and stability of the implant-supported prosthetic. To proceed with immediate loading, 120 Ncm of composite insertion torque has been suggested as a quantitative threshold. Initial recommendations advocated each implant have 30 Ncm of insertion torque. Later studies reported as little as 15 Ncm of insertion torque on a single, vertically stable implant.[5,58] Isolated implants with low insertion torque may benefit from tilting both anterior and posterior implants to increase secondary stabilization.

Dense, atrophic mandibles present a different subset of surgical challenges. All implants often extend through the inferior cortex. The apical proximity of two implants perforating the inferior cortex may increase the risk of mandibular fracture. This concern is diminished by directing anterior implants toward the midline producing a double "V" pattern when viewed on an orthopantomogram.[59,60]

Following implant placement, multiunit abutments are placed and torqued to manufacturer recommendations. In cases where ample keratinized tissue is present, soft tissue can be judiciously excised to aid in closure. Small, transalveolar osteotomies (i.e. "bone holes") are created to allow soft tissue to be sutured in tight proximity to the underlying bone. Soft tissue is reapproximated with resorbable suture using a combination of individual and running sutures. The patient is then turned over to the prosthodontic team for conversion. (**Figure 15**)



A)



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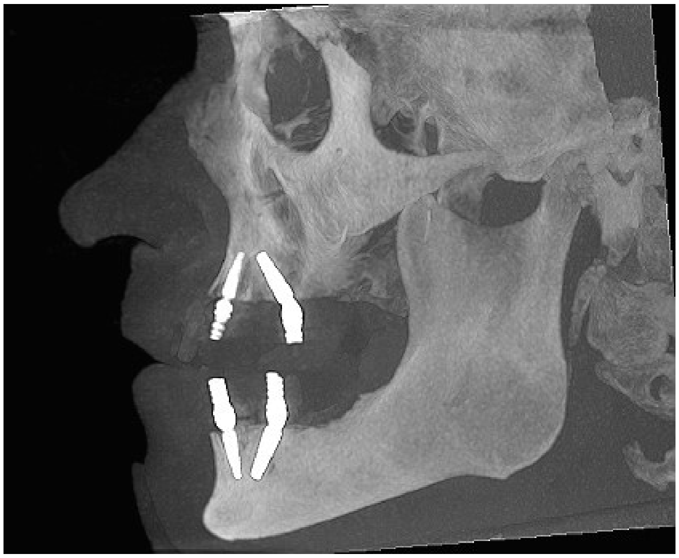

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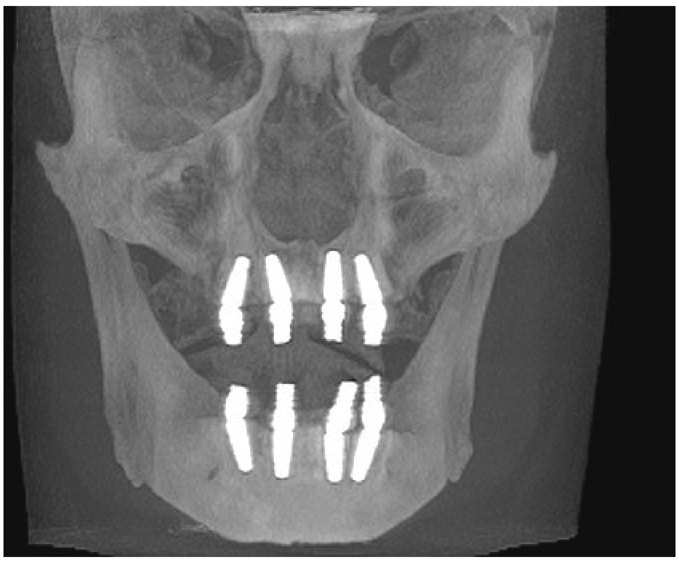

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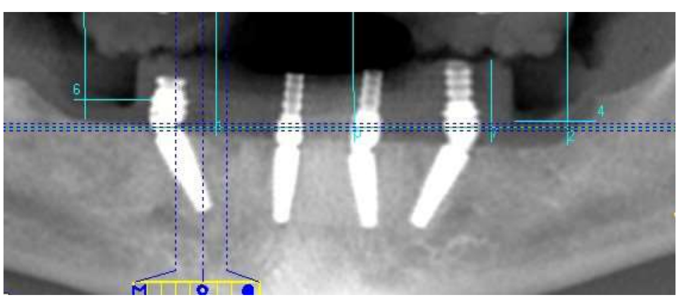

F)

Figure 15. ***A***, *Occlusal view after abutment selection and soft tissue closure of mandibular arch.* ***B***, *Immediate, post-op smile.* ***C***, *Intraoral view of immediate, post-op provisional restoration.* ***D***, *Post-op lateral ceph radiograph.* ***E***, *Post-op radiograph.* ***F***, *Post-op radiograph.*

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