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Evidence-Based Criteria for Differential Treatment Planning of Implant Restorations for the Maxillary Edentulous Patient

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Abstract

Since the introduction of the endosseous concept to North America in 1982, there have been new permutations of the original ad modum Branemark design to meet the unique demands of treating the edentulous maxilla with an implant restoration. While there is a growing body of clinical evidence to assist the student, faculty, and private practitioner in the algorithms for design selection, confusion persists because of difficulty in assessing the external and internal validity of the relevant studies. The purpose of this article is to review clinician- and patient-mediated factors for implant restoration of the edentulous maxilla in light of the hierarchical level of available evidence, with the aim of elucidating the benefit/risk calculus of various treatment modalities.

Restoration of the maxillary edentulous patient with implants is often more challenging than the mandibular arch due to anatomic, biomechanical, and esthetic considerations. Maxillary bone density is predominantly quality 3, as opposed to the mandible, characterized more commonly as quality 2, using the Lekholm-Zarb classification, which has been correlated to primary implant stability.[1,2] Microcomputed tomography has recently shown the mandible to have 1.8 times the bone mineral density of the maxilla.[3] The resorptive pattern of the edentulous maxilla is superiorly and medially directed, resulting in limitations in both height and width of the bony foundation for implants. In contrast, the progressive atrophy of the mandible often leaves a significant depth and width of basal bone anteriorly to accommodate implants.[4] Biomechanically, the antagonist jaw of a maxillary implant prosthesis is more frequently opposed by anterior teeth or implants than mandibular implant restorations are, leading to higher loading forces.[5] In addition, the rigid maxilla does not have the shock-absorbing effect seen in the cantilevered mandible and may not tolerate applied forces equally.[6] Esthetically, a maxillary implant reconstruction is more demanding due to the impact on appearance of maxillary lip support, lip line, and the gingival and tooth display.[7] The resorptive pattern of the maxilla, when extensive, may also lead to dissatisfaction with certain prosthetic designs, since almost 90% have a smile extended to second premolars,[8] which impacts buccal corridor esthetics.[9] Given these risk factors, it is not surprising that the survival rate and patient satisfaction of maxillary implant prostheses is lower than similar data reported on the mandible.[10-13] Because of these challenges, there continues to be controversy on the appropriate implant treatment for the edentulous maxilla.

Our purpose is to review the indications and prosthetic design recommendations when considering the overdenture (IOD), fixed complete denture (IFCD), and metal ceramic (MC) options.[14] The faculty at the University of the Pacific Arthur A. Dugoni School of Dentistry (San Francisco, CA) has reviewed these guidelines for evidence-based student clinical decision-making in accordance with the Commission on Dental Accreditation (CODA) mandates. The level of evidence varies in each section of the discussion and will be quantified based on Sackett et al's[15] hierarchy (Table 1). A MEDLINE search was conducted along with a hand search for articles published over the last 25 years on implant restorative treatment for the maxillary edentulous patient and reviewed by each author.

General considerations for implant therapy

Complete denture principles are the foundation for determining the anatomic, functional, and esthetic blueprint for an

Table 1 Sackett's hierarchy of evidence[15]

Level of evidence	Description
1A	Systematic review of randomized controlled trials (RCTs)
1B	RCTs with narrow confidence interval
1C	All or none case series
2A	Systematic review cohort studies
2B	Cohort study/low quality RCT
3A	Systematic review of case-controlled studies
3B	Case-controlled study
4	Case series, poor cohort case controlled study
5	Expert opinion

implant rehabilitation of an edentulous patient. Systemic, local, and patient-mediated concerns are the triad of factors that will influence the suitability and design preference for an implant restoration of the edentulous maxilla, given the available evidence. Systemic risks for implant therapy have been elucidated in a number of publications,[16-23] although the level of evidence indicative of absolute and relative contraindications is low, due to heterogeneity of studies and lack of standardization of populations.[20,24] Emerging evidence, although weak, suggests a correlation between genetic traits and disruption of osseointegration.[25] Local factors influencing implant treatment include bone quality,[26] degree of bone resorption,[27] previous implant failure,[28,29] jaw classification,[30] lip and facial support needs,[31] intermaxillary space,[32] exposure on smile of the transition line between prosthesis and mucosa,[33] and discrepancy of the arches.[34] Patient-mediated factors impacting prosthetic design options may include financial estimates,[35] total risk analysis including adjunctive procedures,[36,37] treatment time,[38] aftercare burden,[39,40] hygiene access,[14] morbidity,[41] phonetics,[27,32] and esthetics.[6,42] The evidence that documents systemic risks is predominantly from level 2B and 3A. The evidence supporting the influence of local factors ranges from level 2B to 5. Patient-mediated factors affecting design options are documented mainly with level 2A to 3B evidence.

Indications for implant restoration of the edentulous maxilla

Quality of life (QoL) outcomes were evaluated in a systematic review, including 18 randomized controlled trials, comparing complete dentures and IODs for the edentulous maxilla.[43] Although high satisfaction ratings were reported for maxillary implant prostheses, the overall ratings were not significantly greater than for a complete denture. In a crossover study by de Albuquerque et al,[44] 13 patients were restored first with a new maxillary and mandibular denture and then with a maxillary IOD (with or without palatal coverage) opposing an IFCD; however, ratings with the implant prostheses were not significantly higher than for new conventional maxillary prostheses. While there have been conflicting reports comparing patient satisfaction of IOD and CD,[45,46] indications for an implant prosthesis include anatomic morphological limitations precluding adequate stability and retention for a CD, patient intolerance for palatal coverage, and treatment of the refractory gagger.[47]

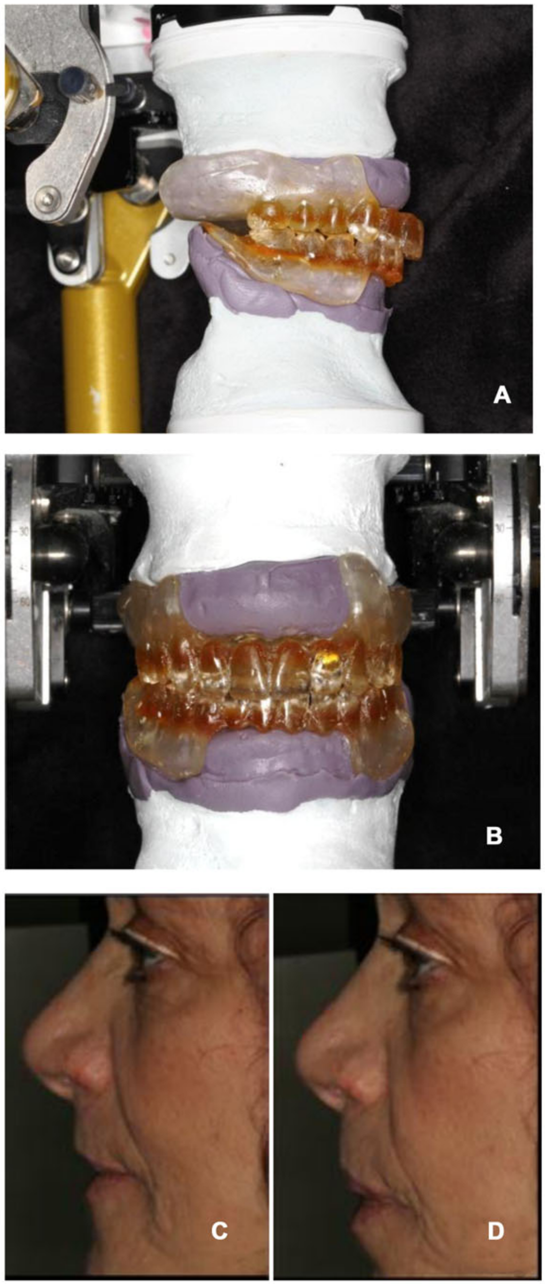

Figure 1 (A) Sagittal view of horizontal defect of pre-maxilla region using an anterior flangeless duplicated denture. If the teeth are appropriately placed for lip support, a metal ceramic (MC) restoration is not advised. (B) Frontal view of vertical extent of residual ridge resorption. (C) Facial profile with no prosthesis in place. (D) Facial profile with flangeless denture in place demonstrating excessive lip support. With appropriate anterior set-up, an MC restoration is feasible.

Evidence supporting the indications for an implant prosthesis on the edentulous maxilla range from level 2A to 3B.

Selection of fixed or removable implant prosthetic design

While there has been ambiguity in the literature regarding patient preferences for a fixed or removable implant prosthesis,[14,48] each has advantages. Removable designs allow for facial scaffolding and dental esthetics for certain jaw and lip morphologies,[14,30,49] improved hygiene access (except with the MC design),[48,50] latitude in positioning of implants,[32,49] ease in reconciling arch discrepancies,[32] and initial cost savings.[14,27] Fixed prostheses offer retention security,[34] enhanced chewing of hard foods (compared to implant- and tissue-borne overdentures),[48] and reduced maintenance.[40] When MC restorations were compared to IFCD prostheses, the QoL ratings were higher for the former design due to esthetic and functional assessments.[51] Given the relative benefits of these designs, a comprehensive examination and diagnosis is of utmost importance to guide the patient in making appropriate treatment decisions. Selection of fixed or removable designs is documented by level 2B to 3B evidence.

Three assessments are critical to a proper selection of prosthetic design: esthetic factors, occlusal vertical dimension (OVD), and radiographic data.[11,12,14,30,48,52,53] The preference of a removable design will be influenced by the need for lip and cheek support, which often can be predicted by the thickness of a buccal flange of an existing complete denture.[54] Duplicating the complete denture and removing the anterior flange can be diagnostic in determining if the maxillary anterior teeth are sufficient to provide lip and facial support (Fig 1). If the anterior/posterior resorption exceeds 10 mm, a removable design is indicated.[55] Secondly, maximum upper lip elevation on smiling will divulge if the prosthetic-tissue junction will be hidden (Fig 2A), or if there may be potential esthetic problems with this fixed design.[56] Without the denture in place, if the alveolar ridge is displayed during smiling, the use of a buccal flange in a removable prosthesis may be advisable (Fig 2B).[30] However, an IFCD may be selected if an ostectomy has been well planned and executed before implant placement to assure that the bony platform is superior to the most apical position of the lip on exaggerated smile.[57] Bidra[7] also reported that class II division 2 patients with a terminal maxillary dentition would benefit from orthodontic intrusion of the anterior sextant before extraction, availing them of an IFCD option after extraction. A high smile line may also be challenging in an MC restoration because of the difficulty of achieving natural-appearing papillae and symmetrical gingival scalloping.[58,59] This feature is more commonly found in females who demonstrate a higher lip line (1.5 mm on average[60]) than males. Esthetic factors critical to prosthetic design selection are supported by level 3B to 5.

The OVD will often have functional and esthetic ramifications when treatment planning the patient with a maxillary edentulous arch.[61] While no single method has been established to determine OVD, the use of physiologic rest position (VDR), swallowing, phonetic, esthetic, and facial measurements all may contribute to the analysis.[62,63] The appropriate interocclusal distance (facial vertical space between VDR and OVD) is about 3 mm for a skeletal class I, but may be less for a class III and more for a class II.[64] If the existing maxillary denture has been constructed at the appropriate OVD, and the anterior and posterior planes of occlusion are suitable, based on esthetic,[65] phonetic,[66] and biometric references,[67] a duplicate denture/radiographic and surgical template can be fabricated.[68] If the existing denture is not acceptable, an idealized wax-up is required before duplication. AbuJamra et al[69] described a laboratory technique to visualize the interarch space available for implant prosthetic restoration of an edentulous patient. Silicone putty impression material was used to form a resilient cast and an external mold from an approved denture. The denture and resilient cast were mounted on an articulator at the prescribed OVD, and spatial relationships visualized in 3 dimensions when removing the denture from the resilient cast (Fig 3). For a Locator-retained IOD (Zest Anchors, Inc., Escondido, CA; Fig 4), 8 to 9 mm of intermaxillary space (from crest of soft tissue to antagonist occlusal plane) is recommended; for a resilient bar IOD (Dolder bar; Sterngold, Attleboro, MA; Fig 5), 12 mm; for a milled bar IOD (Spark-eroded milled bar; Dental Arts Laboratory, Peoria, IL; Fig 6), 11 mm; for an IFCD (Fig 7), 11 to 12 mm, and for the MC design (Fig 8), 7 mm.[70,71] If insufficient space is available to house the prosthetic components for a desired design, an alveoplasty using a surgical template will be required, based on these measurements.[72] When there is insufficient space, Fajardo et al,[73] using an in vitro study, demonstrated the effective use of glass fibers to strengthen thin acrylic areas, but planning for appropriate acrylic thickness is recommended. The impact of OVD on pretreatment protocols, anchorage selection, and maintenance is supported mainly by level 4 and 5 evidence.

Treatment planning the patient with an edentulous maxillary arch benefits from the use of a radiographic template in conjunction with an orthopantomogram and/or a CBCT scan, using appropriate selection criteria.[74,75] This allows a prosthetically driven treatment plan and assessment of the available bony height, width, and possibly density.[76,77] The Hounsfield scale has been used to evaluate bone density (with the aid of software programs) along with resonance frequency analysis and insertion torque measurements to make a more objective assessment of the bone quality.[78] When the volume of bone is compromised, sinus augmentation has been commonly used to increase the alveolar bone height prior to implant placement in the posterior maxilla.[79-81] However, the intermaxillary relationship should always be kept in mind, as sinus grafting may represent only part of the reconstructive procedure to rectify limited bone volume.[37] Wallace and Froum,[82] in a systematic review on sinus grafting, reported a mean implant survival rate of 91.8%; more favorable outcomes with roughened implants; particulate versus block grafts; use of a membrane over the lateral window; but not with the use of platelet-rich plasma. In a retrospective multicenter review on sinus grafting, smoking habits of >15 cigarettes/day and residual ridge height <4 mm were significantly associated with reduced implant survival.[83] Given the paucity of evidence evaluating short implants[84] in the restoration of maxillary edentulous patients, as opposed to the partially edentate or mandibular edentulous patients,[84-86] it is still unclear when sinus lift procedures are needed. A Cochrane systematic review noted that, while conclusions are

Figure 2 (A) Exaggerated smile of patient with maxillary fixed complete denture (IFCD) hiding the prosthetic-tissue junction. (B) Display of residual alveolar ridge without any prosthesis in place.

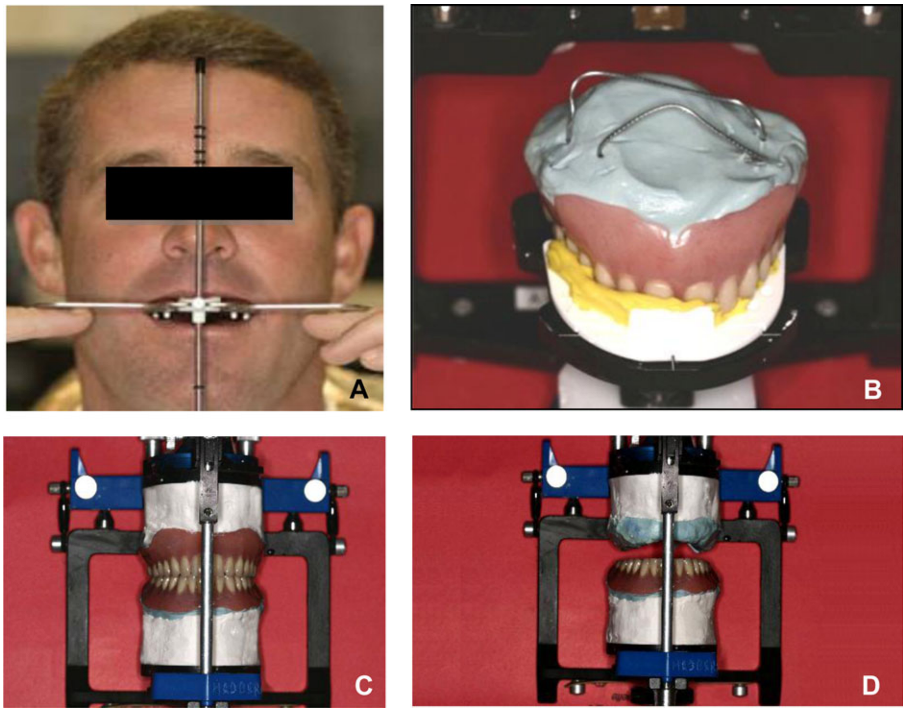

Figure 3 (A) Facebow registration using Kois Facial Analyzer (Panadent Corp, Grand Terrace, CA). (B) Mounting of the maxillary denture with laboratory putty in the intaglio surface with paper clips to retain mounting stone. This will allow a resilient cast. (C) Maxillary and mandibular dentures on resilient casts, mounted on the articulator at the appropriate occlusal vertical dimension (OVD). (D) Measurement of space allowance before prosthetic design is selected. If insufficient space, the amount of required alveoloplasty can be visualized.

based on small trials with short follow-up, if the residual native bone height is 3 to 6 mm, a crestal approach to lift the sinus lining and place 8 mm implants may lead to fewer complications than a lateral window approach to place longer implants.[87] No significant relationship between crown-to-implant ratio and marginal bone loss has been established, at least when the C:I is <3:1.[88] However, esthetic consequences of altering normal anatomic relations may be problematic.[89] Assessment of radiographic data and its influence on treatment planning of implants in the edentulous maxilla is documented predominantly by level 2A to 3B.

Consensus statements on surgical techniques to augment the deficient maxillary edentulous ridge for implants noted that most studies are retrospective in nature.[90] Autogenous onlay bone grafting procedures supporting implants have survival rates slightly lower than those placed in native bone.[37,90] Implants placed in augmented sites opposing unilateral occlusal support showed the highest implant failure rate.[90] Split-ridge and expansion techniques are effective for correction of moderately resorbed edentulous ridges in selective cases, and survival rate of implants following this technique are similar to success in native bone.[90] The use of a graftless approach with

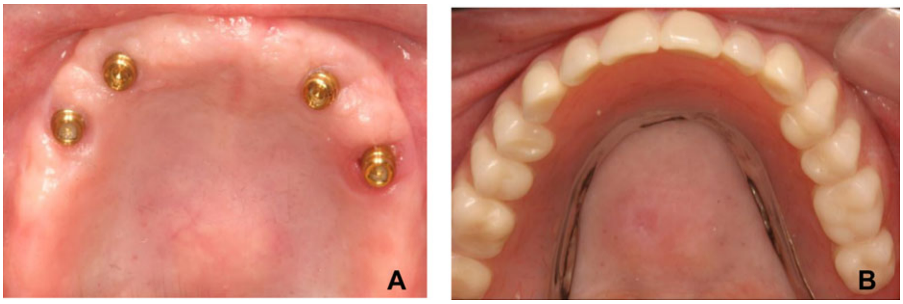

Figure 4 (A) Locator abutments evenly distributed for maxillary overdenture. (B) Suprastructure overdenture in place over locator abutments. Metal reinforcement adds fracture resistance.

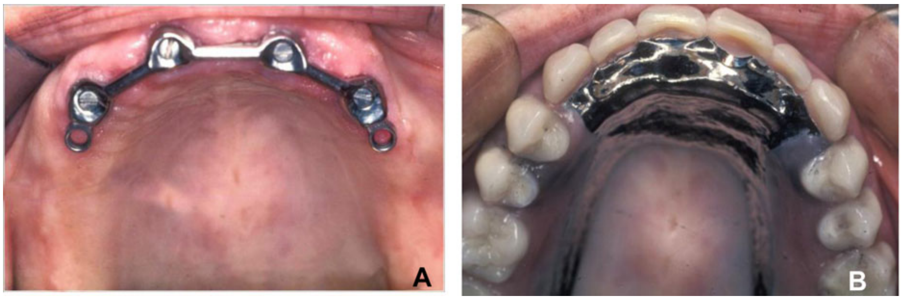

Figure 5 (A) Dolder bar anchorage system. (B) Suprastructure in place over Dolder bar.

pterygomaxillary implants,[91,92] zygomatic implants,[93-96] and/or tilted implants,[97-99] has been used with high reported success when there is inadequate vertical bone for orthodox implant placement; however, in a 2009 review, Att et al[96] reported that more than half of the 42 studies culled failed to detail the prosthetic outcomes. It is also important to keep in mind that successful implant/prosthodontic outcomes are linked to the level of operator experience.[100,101] Most importantly, when there is a need for additional surgical or interdisciplinary intervention to optimize the site for implants for a particular prosthetic design, a risk, benefit, cost, alternative analysis is recommended as part of the patient's informed consent. Surgical procedures to augment the deficient edentulous maxilla are documented with level 2A to 3A.

Figure 6 Implant fixed complete denture.

The implant overdenture

In a systematic review, the survival of maxillary implant overdentures was reported to be 93% after at least a 5-year follow-up.[9] The level of evidence is low because of the heterogeneity of the prosthetic methodologies in the included studies, which have varying implant type and number, anchorage systems, and suprastructure designs. Implant overdentures can be classified as either implant-mucosa or implant-supported prostheses. Implant-supported overdentures do not have a mucosal rest and do not allow movement.[49] The advantage of an implant-supported prosthesis is a decrease in prosthetic maintenance, which may compensate over time for initial higher costs.[85,102,103] Decisions regarding the optimal number of implants, anchorage system, suprastructure design, expected maintenance, and immediate loading protocols remain controversial.

Number of implants

In a recent systematic review, Rocuzzo et al[104] found no studies on the on the optimal number of implants for maxillary implant-supported overdentures. In a recent consensus report, Godfredsen et al[105] noted that there were no RCTs available to demonstrate that a particular number of implants for maxillary IODs offered better biological, technical, or patient-mediated outcomes. However, Balaguer et al[11] in a longitudinal prospective study (36- to 159-month follow-up) of 107 maxillary overdentures reported a significantly higher implant survival with six implants compared to four. In a meta-analysis on maxillary

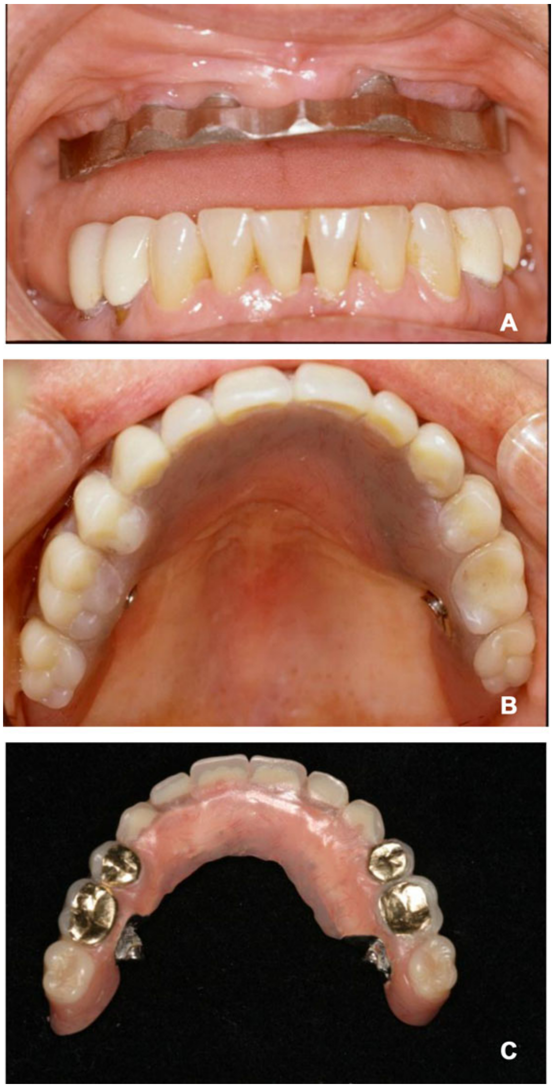

Figure 7 (A) Milled bar mesostructure for overdenture. (B) Suprastructure milled bar overdenture with swivel latches engaged on palatal shelf in first molar region. (C) Gold occlusal design on posterior teeth to thwart attrition.

IODs, Slot et al[106] also reported a statistical difference in four- and six-implant designs. Varying conclusions may be due to heterogeneity in inclusion criteria and overdenture design as well as the low quality of evidence in maxillary IOD studies.[9] Notwithstanding these data, there appears to be a consensus that a minimum of four implants is recommended for a maxillary IOD, evenly distributed over the arch, for a palateless design.[4,32,107] The distribution and number of implants may have a significant impact on applied load, as was demonstrated by an in vitro study.[108] When the patient presents with a heavy smoking habit, previous failure with implants, or bruxism, more than 4 implants are advised.[10,29] The evidence supporting the number of implants appropriate for an implant overdenture ranges mainly from 1A to 2C, with consensus statements from level 5.

Anchorage design/maintenance

In a systematic review, an assessment was made on the influence of maxillary IOD splinted and unsplinted anchorage systems on peri-implant indices and patient satisfaction.[109] There were no significant differences between these designs, except the bar group had reduced maintenance. These data were replicated by an earlier systematic review, a recent Cochrane review, and a 5- to 8-year retrospective clinical study.[49,53,110] Despite these conclusions, there is a lack of standardization of the anchorage design and superstructure, limiting the strength of the evidence.[111] For example, ball and Locator (Zest anchors) attachments have been shown to have different rates of prosthodontic complications, but without reference to number or distribution of implants, palatal coverage, or status of opposing arch.[112] Rigid overdenture designs, with a milled bar and a frictional overcasting that prevents prosthesis rotation, have reduced maintenance in comparison to resilient anchorage designs.[47,102,113] Furthermore, with this system, a number of attachments allow for a biomechanical behavior similar to a fixed prosthetic implant restoration including a spark-eroded swivel latch (Fig 7B).[114,115] One overarching problem has been quantification of what constitutes maintenance. Some have classified it in terms of number of appointments,[107] others on the basis of severity: major non-retrievable, major retrievable, and minor retrievable.[116] In summary, for patients requiring facial scaffolding, hygiene access, and retention security, a rigid overdenture design with locking attachments has demonstrated high patient satisfaction as long as the patient has adequate dexterity.[102] In vitro studies have demonstrated reduced center point deviation with milled titanium versus heavier cast frameworks,[117,118] but there seems to be no significant impact on long-term function of restorations.[119] Solitary anchorage designs, on the other hand, may be helpful in patients with limited financial resources, poor oral hygiene, and limited keratinized tissue.[120] Overall, a bar has been recommended when restoring divergent implants of more than 10°.[121] With the resilient designs, a 17% to 22% loosening or fracture rate has been reported in the first year.[4,107,122] Regardless of the anchorage design, the IOD is prone to denture tooth attrition, and a number of materials have been recommended to resist wear (Fig 7C).[123,124] Finally, it is apparent that controlled trials on a larger number of participants comparing types of attachments, superstructure designs (including cast metal-[125,126] or fiber-reinforced[127,128] denture bases for resilient superstructures), status of opposing arch, palatal contour, and cost and time analyses are lacking for the maxilla.[13,115] The evidence supporting anchorage design decision making is mainly level 1A to 3A.

Immediate load protocols

While there are numerous advantages in immediately loading a maxillary overdenture, including shortening the provisional prosthetic period and overall treatment time, few patient-mediated benefits are documented.[129] The shortcomings in fitting the superstructure to soft tissues that will change weeks later, need for multiple relines, and contamination of the surgical site with impression material or methyl methacrylate all need to be considered in the clinical decision making. Early loading (between 7 days and 8 weeks) has been more frequently

Figure 8 (A) Screw-retained metal ceramic (MC) design. (B) Gingival-cervical crown junction of the MC design.

used with the selection of roughened implant surfaces and may avoid many of the drawbacks of immediate loading.[129] Systematic reviews have noted that early and conventional loading protocols are better documented than immediate loading and seem to result in fewer failures compared to immediate loading.[129-131] Loading protocols are documented mainly with level 2A to 3B evidence.

The implant fixed complete denture

Two groups comprising 76 and 109 patients were treated with 450 and 670 implants, respectively, for an IFCD, 15 years apart, and followed for 5 years.[132,133] The two cohorts reflected changes in the implant and prosthetic protocol from 1987 to 2001. Approximately half of the implants in the second cohort received a roughened implant, and all other patients received machined implants. For the late group, the prosthesis was designed more for esthetics by using shorter abutment cylinders and placing the prosthesis closer to the tissue. The 5-year cumulative implant/prosthetic survival rate was 93.4%/97.1% and 97.3%/100.0% for the early and late group, respectively. Patients in the late group had fewer complications with diction and veneer fracture. This underscores the questionable validity of combining results from different time periods.[134] These data were based on patients receiving an average of 6 implants. Assessments regarding the optimal number of implants, framework design, expected maintenance, and immediate loading protocols will facilitate decisions regarding the IFCD, given the best available evidence. The data on IFCDs is supported by level 2A to 2B.

Number of implants

No comparative trials, let alone RCTs, were available to assess the optimal number and position of implants for a maxillary IFCD. Most of the included studies in a systematic review reported on complication rates for IFCDs supported by 4 to 6 implants without addressing how many reconstructions had 4, 5, or 6 implants.[135] A descriptive study reviewing long-term evidence on implant and prosthodontic survival rates of fixed rehabilitations and reported prosthetic protocols with ≥6 implants showed a higher survival rate than those with <6 implants.[136] The failure of one of the implants with <6 implants could jeopardize the prosthodontic survival and may explain why selected articles showed a lower survival rate with this number.[136] Risk factors such as compromised quality/quantity of bone and high applied forces should also be considered when determining the number of implants.[4] The number of implants for an IFCD is documented by level 2A evidence.

Framework design

Framework fracture continues to be reported during follow-up periods with IFCDs.[137-139] The most common reasons for these findings were insufficient cross-sectional dimension distal to the terminal implant, poor alloy choice, excessive cantilever length for the anterior/posterior span, and inadequately designed frameworks.[140] Stewart and Staab[141] showed that the "I" and the "L" shaped configurations had the most fracture resistance for cantilevered frameworks. The recommendations that cantilevers may extend at most to 1.5× the anterior/posterior span was empirically established and should be modified by the estimated applied forces (e.g., parafunction, skeletal form, opposing dentition) and number of implants.[140,142] Given that the population of IFCD patients may generate as much as 240 N,[143] current materials are able to accommodate these loads without deformation, as long as the height of the bar is adequate.[143] Optimal thickness will depend on type of metal, number of implants, supporting bone, and loading forces. A broad range of recommendations has been published for the dimensional protocol of cast bars (3–7 mm) and milled bars (2.5 mm).[140] However, a minimum of 4 × 4 mm appears to be a safe dimension for both. Cast noble alloys (gold, silver, palladium, and platinum) and titanium alloys have been used widely and have similar yield strength (825–900 MPa) with similar long-term outcomes.[119,144] Retentive elements (nailhead features, loops, and undercut areas) for denture base materials should be incorporated in the framework design, including posts for anterior teeth, and primed with a silicoater. A framework can only be fabricated after an idealized wax-up dictates its appropriate three-dimensional location by the use of a matrix. Different designs have been investigated. A retrospective study on all-ceramic crowns cemented onto a CAD/CAM titanium framework, with pink ceramic, has reported a 92.4% prosthetic survival rate with a 10-year follow-up, albeit on only 28 maxillary prostheses.[145] Clinical long-term data are lacking for the use of extensive implant-borne zirconia frameworks.[146-148]

Framework design principles for the IFCD are documented with predominantly level 2B to 3A evidence.

Maintenance

A systematic review of the biologic and technical complications with IFCDs reported a prosthesis success rate (free of complication) of 8.6% after 10 years.[149] The most common prosthesis-related complication was chipping or fracture of the veneering material (33.3% at 5 years and 66.6% at 10 years).[149] This has been attributed to material failure, framework misfit, inadequate prosthetic space, excessive cantilevers, and laboratory errors. The most common implant-related complication was peri-implant bone loss (>2 mm) at a rate of 40.3% after 10 years. The most frequent prosthesis-related biologic complication was hypertrophy of the tissue around the IFCD (13.0% and 26.0% after 5 and 10 years, respectively).[149] Ten-year results from two separate studies quantified framework fracture at 9.8%.[119,150] A prospective RCT 10-year study on cast titanium-resin prostheses on 24 patients reported a total of 4.7 resin-related complications per prosthesis, which lingual gold onlays reduced.[151] Purcell et al,[152] in a retrospective chart review with an average recall time of almost 8 years, found that patients were 50 times more likely to replace posterior teeth at the 5-year mark than at the 2-year mark. The use of urethane dimethacrylate teeth has been suggested to reduce wear (SR Phonares NHC anterior, SR Phonares NHC posterior; Ivoclar Inc., Amhurst, NY).[153] Mofitt et al[154] also speculated that tooth debonding or fracture will continue to be a formidable challenge with this design. Both antagonist occlusal plane evaluation and occlusal equilibration, especially in excursions (including lateral protrusive pathways), are critical to reduce mechanical complications. Maintenance data ranges mainly between level 1A and 2B.

Immediate loading protocol

With assiduous patient selection, use of roughened implant surfaces, immediate loading (given a 30 Ncm insertion torque) with an IFCD has been shown in a recent meta-analysis to have the same effect on implant survival (90.4% to 100% from 1 to 10 years of follow-up) and complications as with early or conventional loading.[155] Nevertheless, most follow-up times are short, and the investigations demonstrate heterogeneity, including number of implants, which point to the need for comparative studies on different loading protocols reporting complications over a period of greater longevity.

The effective use of tilted implants for terminal abutments for an All-on-4 IFCD has enabled this design to be more universally applied. A meta-analysis demonstrated that there are no more biomechanical or biologic complications with tilted implants as compared to vertically placed implants.[97] Long tilted implants parallel to the anterior wall of the sinus allow for high levels of primary stability, a longer occlusal table, and a shorter cantilever when posterior native bone is unavailable for vertical implants.[156] Patzelt et al[157] completed a systematic review, including 1201 All-on-4 immediately loaded prostheses (within 48 hours), and reported a 99% implant and prosthesis survival rate for 36 months for the maxilla or mandible. Seventy-four percent of the implant failures were documented in the first year. The major prosthetic complication was fracture of the all-acrylic transitional prosthesis, similar to Hinze et al's findings.[158] The conclusions of the systematic review, however, were that the evidence was limited by the quality of the available studies and the lack of long-term outcomes. For example, Browaeys et al[159] reported 30% of the implants in an All-on-4 concept had almost 2 mm of marginal bone loss after 3 years, but the study was marred by a small sample size, and a multivariate analysis on host factors could not be assessed.

A retrospective analysis of the associated risk factors when restoring 285 maxillae with an All-on-4 approach revealed a number of associated risk factors.[160] Opposing natural dentition (unstable occlusal plane), reduced bone density, male gender, and parafunction were linked to implant failure. The author recommended patient profiling for treatment planning additional implants and/or delayed loading. The evidence supporting the All-on-4 concept is Level 2A-2B.

The metal ceramic design

For patients with sufficient resources and limited alveolar resorption, an MC design can offer a highly esthetic, biocompatible, functional, and hygienic restoration with reduced bulk and maintenance as compared to the IOD and IFCD designs.[34,161] However, both surgical and prosthodontic acumen is required, since the implants must be congruent with the crowns, and the creation of a natural morphology of the tooth/tissue junction is rigorous. Complete fixed, segmented rehabilitations supported by 6 to 8 rough surface implants have been documented in a review with a 96.4% prosthodontic survival rate at the 10-year endpoint.[137] No statistical differences have been reported between segmented and one-piece full-arch maxillary reconstructions and in the interest of protocol simplification, passive fit, laboratory steps, and repair; 1 or 2 anterior and 2 posterior splinted segments are practical.[136,162] In an ovoid dental arch, implants in the canine positions and at least one additional implant in the central incisor position will resist forces created by an anterior lever arm, reducing stress on the abutment screws.[161] Early approaches with machined implants achieved a 5-year cumulative implant survival rate of 98.5% with immediate implantation, without immediate loading.[163] Immediate loading of immediately placed implants suffers from a lack of scientific validation by clinical data.[130] Following a maximum observation period of 10 years (median 29 months) on 25 patients, immediate loading of rough-surfaced, screw-type implants in the healed edentulous maxilla for a MC restoration demonstrated a 98.2% success rate for implants and 88% for patients.[164] The time of implantation did not influence survival or success rates. The authors did express caution when using more than 10 implants or lengths of 10 mm or less.[164] The evidence documenting the MC restoration is level 2A to 3B.

Maintenance

There is a dearth of studies on complications with the MC design with observation periods of at least 5 years on conventionally, early, or immediately loaded implants in the completely edentulous patient.[149] Two studies investigating mainly partially edentulous patients have reported a dominant and costly

Table 2 Algorithm for decision making in treatment planning the implant restoration of the edentulous maxilla

	Limited alveolar resorption	Moderate-to-advanced alveolar resorption	
Prosthetic design	Metal ceramic design	Fixed complete denture	Overdenture
Intermaxillary space allowance	Ideally 7 mm	≥11–12 mm	Locator (≥8–9mm), Bar and clip (≥12 mm), Milled bar with overcasting (≥11 mm)
Local factors	Sufficient bone for implants congruent with crowns positioned for segmented prostheses, esthetic approval of smile design	No display of the prosthetic/tissue junction, facial esthetic approval without flange	Requires anterior flange, discrepant arches easier to reconcile, severe resorption may need adjunctive surgical augmentation or tilted/zygomatic implants
Patient-related factors	Financial acceptance	Preference for fixed, accepting of limited hygiene access	Accepting of a removable design although possibility of a latching device, hygiene access priority
Number of implants	6–8 implants	Five to six implants depending on bone quality/quantity, bruxism, heavy smoking, opposing natural dentition, previous failure with implants	Five to six implants depending on bone quality/quantity, bruxism, heavy smoking, opposing natural dentition, previous failure with implants
Anchorage design	Preferably screw-retained	4 × 4 mm framework with retentive features and tribochemical preparation	Solitary anchors may be indicated if limitations in financial resources, home care facility, or keratinized tissue. A rigid bar system is recommended if divergence of implants and/or high retention needs

Ultimately, clinical judgment and emerging evidence of sound scientific rigor will govern decision making.

complication. Bragger et al[165] calculated a threefold increase in ceramic veneer fracture on implant MC FDPs compared to tooth-supported restorations, after 4 to 5 years of service. Kinsel and Lin[166] found a sevenfold increase in ceramic fracture when the opposing dentition was implant-supported or when the patient was a bruxer. Patients who did not wear an orthotic had twice the odds of porcelain fracture.[166] The impact of occlusal scheme has not been established. Other technical problems, such as prosthetic/abutment screw loosening, of retention of cemented prostheses have been less prevalent than veneer fracture.[167] Biological complications are mostly patient-based and can be related to heredity, susceptibility to peri-implantitis, and poor oral hygiene; when operator error is not an overriding factor.[168] Despite substantial improvements in implant dentistry over time, technical, biological, and esthetic complications are still frequent.[169] This places a premium on retrievability, and if cement-retained units are designed, radiopaque provisional cements are recommended. Longitudinal studies reporting on adverse clinical outcomes are necessary to provide practitioners with evidence-based treatment planning and patients with informed consent.[170] Level 2A to 5 evidence supports the discussion on maintenance of the MC restoration.

Summary

An algorithm has been generated to provide an overview of the decision-making criteria when considering restoring the edentulous maxilla with an IOD, IFCD, or MC prosthesis (Table 2). The implant restoration of the edentulous maxilla continues to be demanding in light of the density and volume of bone, anatomic limitations, antagonist arch presentation, esthetic considerations, and the frequency of biologic and technical complications. Design considerations have been described to assist in treatment planning decision making to improve cost-effectiveness and patient satisfaction. The hierarchical level of evidence supporting the discussion in each section has been graded, and gives credence to the need for more randomized controlled trials and longitudinal comparative studies on larger cohorts.

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