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Concepts for Designing and Fabricating Metal Implant Frameworks for Hybrid Implant Prostheses

Carl Drago, DDS, MS[1] & Kent Howell, DMD, MS[2]

[1] Clinical Director, Eon Clinics, Waukesha, WI, formerly, Associate Professor, Department of Restorative and Prosthetic Dentistry, The Ohio State University College of Dentistry, Columbus, OH

[2] Prosthodontist, Southwest Dental Group, Scottsdale, AZ, formerly, Advanced Prosthodontics, The Ohio State University, Columbus, OH

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Correspondence:
Carl Drago, Eon Clinics, 20700 Swenson Dr., Pewaukee, WI 53072. E-mail: carl.drago@gmail.com

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Abstract

Edentulous patients have reported difficulties in managing complete dentures; they have also reported functional concerns and higher expectations regarding complete dentures than the dentists who have treated them. Some of the objectives of definitive fixed implant prosthodontic care include predictable, long-term prostheses, improved function, and maintenance of alveolar bone. One of the keys to long-term clinical success is the design and fabrication of metal frameworks that support implant prostheses. Multiple, diverse methods have been reported regarding framework design in implant prosthodontics. Original designs were developed empirically, without the benefit of laboratory testing. Prosthetic complications reported after occlusal loading included screw loosening, screw fracture, prosthesis fracture, crestal bone loss around implants, and implant loss. Numerous authors promoted accurately fitting frameworks; however, it has been noted that metal frameworks do not fit accurately. Passively fitting metal implant frameworks and implants have not been realized. Biologic consequences of ill-fitting frameworks were not well understood. Basic engineering principles were then incorporated into implant framework designs; however, laboratory testing was lacking. It has been reported that I- and L-beam designs were the best clinical option. With the advent of CAD/CAM protocols, milled titanium frameworks became quite popular in implant prosthodontics. The purpose of this article is to discuss current and past literature regarding implant-retained frameworks for full-arch, hybrid restorations. Benefits, limitations, and complications associated with this type of prosthesis will be reviewed. This discussion will include the relative inaccuracy of casting/implant fit and improved accuracy noted with CAD/CAM framework/implant fit; cantilever extensions relative to the A/P implant spread; and mechanical properties associated with implant frameworks including I- and L-beam designs. Guidelines will be proposed for use by clinicians and laboratory technicians in designing implant-retained frameworks.

Edentulous patients have reported difficulties in managing complete dentures. Marachlioglou et al reported that patients had higher expectations regarding their complete dentures than did the dentists who treated them. Dentists reported that dentures would bring fewer benefits to patients than did the patients.[1] Patients with complete dentures have also reported decreased masticatory function in that they avoided certain food types because they were simply unable to chew them.[2] Lin et al reported the results of a clinical study investigating the relationship between chewing ability and diet among elderly edentulous patients. Approximately 58% of the subjects reported dissatisfaction with their dentures; 51% reported discomfort on chewing. Patient satisfaction or dissatisfaction with their dentures during mastication significantly impacted the diet of these elderly edentulous patients.[3]

Clinical denture issues may be related to loss of alveolar bone after tooth extraction. Dental implants, in addition to providing increased retention and support for prostheses, also have been reported to maintain alveolar bone volume.[4] Endosseous implants are thought to maintain bone width and height as long as implants remain anchored in bone with healthy, biologic attachments.[5]

Historical perspective

Two of the objectives regarding definitive implant prosthodontic treatments were the design and fabrication of accurately fitting, strong metal frameworks to splint multiple implants. Frameworks also served as the foundation for retaining fixed-implant prostheses on a long-term basis. Over the years,

Figure 1 Clinical image of a mandibular fixed hybrid prosthesis approximately 13 years post insertion. Note the extreme wear/abrasion of the artificial teeth; the implant framework on the patient's right side was exposed secondary to occlusal abrasion.

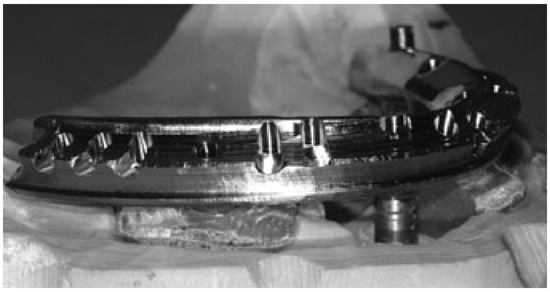

Figure 2 Clinical image of a mandibular implant CAD/CAM framework for a fixed hybrid implant prosthesis. This framework was made using an L-beam design. Facial and lingual finish lines were machined for finishing the processed acrylic resin.

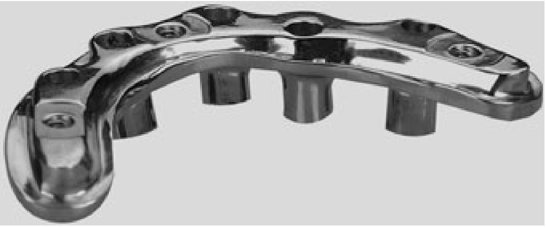

Figure 3 CAD image of a mandibular implant-retained framework designed as an I-bar. The facial and lingual finish lines were machined similar to the L-beam design in Figure 2.

multiple, diverse methods have been used for implant framework design and fabrication; different materials have also been used, including, but not limited to, noble/base metal alloys and various ceramic materials (Figs 1–3).

Original framework designs for fixed hybrid prostheses

Zarb and Jansson[6] stated that frameworks (fixed prostheses) could be designed in one of the two ways: (1) where metal frameworks comprised the bulk of the prostheses, and artificial teeth and minimal denture bases were the only non-metallic components. (2) Implant fixed prostheses consisting mostly of acrylic resin denture bases (wraparound design) and artificial teeth, with minimally sized metal frameworks (Fig 4).[6] Implant treatment was based on basic prosthodontic principles that included preliminary and definitive impressions, jaw relation records, wax try-in, metal framework try-in (with and without the artificial teeth), and insertion of definitive prostheses. Frameworks were fabricated according to the following criteria: bulk for strength, adequate access for oral hygiene procedures, minimal display of metal on the facial and occlusal surfaces, and strategic thinning of implant frameworks to allow for retention of acrylic resin denture teeth and denture bases. In removable partial denture (RPD) design, it was noted that retentive portions of RPD frameworks should allow for 1.5 mm thickness of resin. Thickness was also necessary to minimize the potential fracture of the acrylic resin base material surrounding metal frameworks.[7] These principles have been extrapolated to fixed implant framework design. It is interesting to note that in an early implant textbook, no mention was made of the lengths of the cantilevered segments.[6]

Figure 4 Clinical image of an acrylic resin wrap around mandibular fixed implant hybrid prosthesis. The cast metal framework was completely enveloped within the hybrid prosthesis.

Numerous authors have reported on prosthetic maintenance issues with fixed implant prostheses. Zarb and Jansson noted that implant frameworks were vulnerable to fracture, especially at the junctions between distal abutments and cantilevered segments.[6] Zarb and Schmitt reported clinical problems that included: abutment screw fracture, gold alloy retaining screw fracture, and framework fractures (12/13 occurred in the cantilevered portions of the frameworks).[8] Relative to framework fracture, Zarb and Schmitt suggested design changes including cantilevered segments not exceeding 20 mm, increased cross-sectional surface areas, and using casting alloys with higher yield and tensile strengths compared to the alloys used in original osseointegrated prostheses. They also stated that prosthodontic treatment included a series of clinical steps that were mostly empirical, and that treatment invariably was accompanied by varying degrees of problems (Figs 5 and 6).

Oral/facial symmetries and lip contours may be significantly influenced by appropriate/inappropriate maxillary tooth positions, vertical dimension, and/or the need for flanges of varying thicknesses for lip support.[9,10] Upper lip peri-oral activity may be far more revealing of maxillary gingival tissues than the corresponding activity of the lower lip.

Esthetic demands tend to be more dramatic with maxillary prostheses than mandibular prostheses. As per Zarb and Schmitt,[8] unlike mandibular implant prostheses where hygienic

Figure 5 Laboratory image of a fractured fixed, implant-retained mandibular prosthesis. This prosthesis fractured through the distal cylinder on the patient's right side. The fracture also included the occlusal portion of the implant. The exact cause of this failure was unknown, although the vertical height of the framework appeared to be approximately 3+ mm.

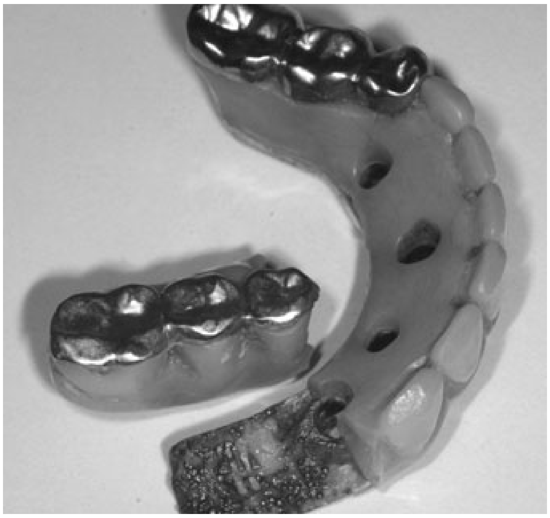

Figure 6 Laboratory image of a fixed, implant-retained mandibular prosthesis where a relatively long distal cantilevered prosthetic segment separated from the metal framework. The implants were placed in a relatively straight line, with minimal A/P spread. Note also the limited vertical thickness of the acrylic resin denture base; this indicated minimal interarch clearance.

type designs have proven to be functionally and esthetically acceptable, maxillary implant prostheses demand different sized and shaped labial/buccal flanges that may or may not compensate for optimal esthetics (including lip support), phonetics, and masticatory function (food impaction between intaglio surfaces and edentulous areas). If flanges are fabricated for upper lip support and phonetics, they may not be readily reduced for access for adequate peri-implant oral hygiene procedures (Fig 7). Maxillary prostheses impact speech significantly more than do mandibular prostheses. Patients have also identified speech as a major factor in perceived satisfaction of their prostheses.[11-15]

Maxillary functional issues are different from those encountered in edentulous mandibles. Maxillary complete dentures tend to predictably restore original soft tissue contours, tooth positions, and arch forms. Maxillary complete dentures, relative to tongue movements, are generally negligible; speech is not usually impaired. Functional demands for maxillary hybrid implant prostheses are complicated in that phonetics may be affected by hybrid designs and contours. Additionally, prosthetic gingival tissues are often required due to resorptive patterns of edentulous maxillae. Resorptive patterns in maxillae are dissimilar to mandibular resorption patterns: maxillae resorb superiorly, posteriorly, and medially; mandibles resorb inferiorly, anteriorly, and laterally.[16,17] Differences in maxillary and mandibular resorption patterns often lead to unfavorable implant and prosthetic relationships between opposing jaws.

Figure 7 Laboratory palatal image of a maxillary fixed, implant-retained prosthesis. Note the junction between the prosthesis and the replica soft tissues in the anterior segment. This type of design is thought to facilitate phonetics.

Frameworks for the original fixed hybrid prostheses were waxed with gold alloy cylinders, cast with silver palladium alloys, and screwed into place with small retaining screws.[8] Fixed hybrid prostheses splinted implants together via a strong, rigid metallic unit that fulfilled the objectives of strength, support, non-tissue impingement, and non-interference to obtain the desired cosmetic results.[6] It is interesting to note that in chapter 15 of *Tissue Integrated Prostheses: Osseointegration in Clinical Dentistry* (Prosthodontic Complications), there was no mention of optimal framework design.[6,18-20]

In an early textbook, Glantz[21] stated that fixed implant prostheses were almost invariably extended distal to the most distal implants to create optimal functional balance between mandibular and maxillary prostheses. He stated that at the time (1985), there was no precise equation for describing functional deformation patterns of fixed prostheses with cantilevered pontics. He offered a complex equation where deformation of implant-retained, fixed prostheses was inversely related to the modulus of elasticity, width, and height (H) of frameworks and positively correlated with the amount of force and length (L) of frameworks. Therefore, for a given alloy with a known modulus of elasticity, taller (height) and thicker (width) frameworks resisted deformation better than thinner or more narrow frameworks. Therefore, the greater the force generated on a given framework, with increased framework lengths (cantilever), frameworks would be more likely to undergo deformation when compared to lesser forces and frameworks with decreased cantilever lengths.

Passively fitting implant frameworks

Traditionally, implant frameworks were fabricated using the lost-wax technique and casting noble alloys. It has been well established that casting errors may be corrected using various soldering techniques.[22-24] It has been consistent from early reports regarding implant frameworks that passive, accurate fits should be obtained between implant frameworks and implant restorative components.[25] It has also been well established that implant frameworks cannot be made to fit passively.[26] Zarb and Jansson identified this in an early textbook by stating that if a clinical passive fit was not obtained, frameworks should be sectioned, an intraoral index made, and then the segments should be soldered.[27] Zervas et al reported in a laboratory study that soldering did not improve the casting misfit of three-unit fixed partial dentures (FPDs).[28] Rubenstein and Lowry reported in another laboratory study that assessed the accuracy of segmental indexing/soldering for full-arch frameworks, using two types of resin, that there were no significant differences noted between alloy/index combinations, except for angular changes around the Y-axis.[29]

Laser-welding of implant frameworks has also been studied. In a study undertaken to describe the effect of laser-welding conditions on material properties of welded frameworks, Uysal et al reported that, within the constraints of their finite element analysis, mechanical failure of welded joints should not be expected under simulated intraoral conditions.[30] Silva et al reported that implant frameworks may show a more precise adaptation between frameworks and implant restorative platforms when segments were sectioned and laser welded.[31] Hjalmarsson et al measured and compared the precision of fit of laser-welded (Cresco) and computer-numeric-controlled (CNC)-milled metal frameworks for implant-supported fixed complete prostheses.[26] Overall, the maximum 3D range of center point distortion was 279 μm. None of the frameworks presented a perfect, completely “passive” fit to any master cast; however, CNC frameworks had statistically significantly less vertical distortion than the Cresco groups. Other reports have resulted in similar findings.[32,33]

CAD/CAM frameworks have been found to fit more accurately than frameworks cast with gold alloys.[34,35] Implant framework fit and its effect on associated peri-implant bone levels has also been researched. Some authors have concluded that a perfect passive framework is impossible to achieve and arguably, unnecessary.[36-38] Although research regarding framework misfit as a cause of peri-implant bone loss is difficult to prove, others have described the value of excellent framework fit for optimal screw mechanics.[39,40]

Prosthetic complications associated with fixed implant frameworks

Prosthetic complications have been defined as treatments, adjustments, or repairs of implant prostheses that became necessary secondary to unexpected events.[41,42] Zarb and Schmitt[5] identified three types of prosthetic complications: structural, cosmetic, and functional. Zarb and Schmitt[8] followed 46 patients treated with 274 implants (49 frameworks) for 4 to 9 years and reported a high incidence of prosthodontic complications associated with fixed implant prostheses: 9 abutment screw fractures (3.3%); 53 gold alloy screw fractures (19.3%); and 13 framework fractures (26.5%). It is important to note that Zarb and Schmitt’s report included patients treated with early prosthetic protocols that included cast alloy frameworks, and minimal understanding of screw mechanics, torque, preload, and A/P spread. Contrast the above results with more recent reports. In a 5-year clinical study, Hjalmarsson et al reported on the clinical outcomes associated with screw-retained fixed implant prostheses made with laser welding versus frameworks made with milled commercially pure titanium. They noted significantly more complications in the laser-welded framework group than in the milled framework group.[43] Ortorp and Jemt reported the results of a 10-year clinical study, and noted the frequency of prosthetic complications was low, with similar clinical and radiographic results for CAD/CAM milled and cast gold alloy frameworks.[44] One prosthesis was lost in each group due to loss of implants; one prosthesis fractured in the CAD/CAM milled group. They noted more maintenance appointments were needed for maxillary prostheses.

Physical properties of metals used in fixed implant frameworks

Cast noble alloys

Noble metals have been defined on the basis of their chemical and physical properties; noble alloys resist oxidation and corrosion by acids. Four noble metals are used in dental alloys: gold, palladium, silver, and platinum. These metals give noble metal alloys their inert intraoral properties. Alloys that contain more than 6% palladium are usually white/silver colored (Tables 1 and 2).[45]

There has been increased use of palladium/silver alloys in implant prosthodontics. These alloys provide mechanical properties similar to type III gold alloys, but at reduced cost. Increased amounts of silver increase ductility and lower hardness; silver also decreases tarnish resistance. Alloys with high palladium contents generally contain limited amounts of other noble metals.

Physical properties such as yield strength, Vickers Hardness, and ductility (% elongation) are properties clinicians and dental laboratory technicians consider when deciding which alloy should be used for dental frameworks.[45] Reproducible procedures resulting in consistent, accurate, strong castings with high yield strengths are critical for long-term successful metal frameworks. Stress resistance of alloys has an impact on the minimum dimensions in critical areas such as connector areas and cantilevers. Elastic modulus is also important because it determines the flexibility of metal frameworks. Flexibility is inversely proportionate to the elastic modulus—an alloy with a high elastic modulus will flex less under load than an alloy with a low elastic modulus. Casting accuracy is also important for fabrication of clinically acceptable frameworks.

Palladium/silver alloys usually contain about 50% to 60% palladium; most of the balance is silver. They generally exhibit satisfactory tarnish and corrosion resistance. The elastic modulus for this group of alloys is the most favorable of all the noble metal alloys and results in the least flexible castings.[45] One disadvantage with this group of alloys does not factor

Table 1 Roles of alloying elements in dental noble alloys

Property	Gold	Platinum	Palladium	Copper	Silver	Zinc	Iridium
Melting point °C (°F)	1063 (1945)	1769 (3224)	1552 (2829)	1083 (1981)	961 (1761)	420 (787)	2443 (4429)
Chemical activity	Inert	Inert	Mild	Very active	Active	Very active	Active
Approximate content (%)	50–95	0–20	0–12	0–17	0–20	0–2	0.005–0.1
Melting	Raises melting point mildly	Raises melting point rapidly	Raises melting point rapidly	Lowers melting point even below its own	Slight effect; may raise or sometimes lower mildly	Lowers melting point readily; in most solders	No effect
Tarnish resistance	Essential	Contributes	Increases tarnish resistance but less than Au and Pt	Contributes to tarnish in flame, or with sulfurous food	Tarnishes in presence of sulfur	Will tarnish, but in low percentages has little effect	Increased

Table 2 Composition and properties of dental noble alloys

	Composition				Vickers hardness		Yield strength psi (MPa)		Ductility % elongation
Type	AU	Pt	Pd	Ag	As cast	Hardened	Quenched	Hardened	
III	74	0	4	12	130	157	38000 (262)	48000 (331)	39.4
IV	68.5	3	3.5	10.5	181	280	56400 (389)	101900 (703)	17
PFM	48.5	0	39.5	0	224	283	70500 (486)	87400 (603)	11

III Firmilay (Jelenko Co, New Rochelle, NY).
IV No.7 (Jelenko Co, New Rochelle, NY).
PFM Olympia (Jelenko Co, New Rochelle, NY).

into frameworks for implant hybrid prostheses—the tendency to change to a green color with porcelain applications.

Cast base metal alloys

Non-precious or base metal alloys are composed of non-noble metals, except for beryllium, a precious but non-noble metal. Most base metal alloys are based on combinations of nickel and chromium, although cobalt/chromium and iron-based alloys are also used. Corrosion resistance for base metal alloys depends on other chemical properties. After casting, a thin chromium oxide layer provides an impervious film that passivates the alloy surface. The layer is so thin that it does not dull the alloy surface. These alloys differ significantly from noble alloys, as they possess significant hardness, high yield strengths, and high elastic moduli. Elongation is equivalent to the gold alloys, but is countered by the high yield strength. Base metal alloys are significantly less expensive than noble alloys, but this may be negated by higher labor costs associated with finishing and polishing procedures. Allergies associated with nickel and nickel-containing alloys have been documented.[46] Inhaling dust from grinding nickel- and beryllium-containing alloys should be avoided.

Milled titanium frameworks

Ti and Ti alloys are well suited for use in clinical dentistry because they have excellent corrosion resistance, low specific gravity, and excellent biocompatibility, are inexpensive, and possess mechanical properties similar to cast gold alloys. Ti and its alloys are difficult to cast due to their high melting points, low density, and reactivity with elements in casting investments.[47]

Milled zirconium frameworks

Zirconia has been available for use in restorative dentistry as a dental ceramic replacement for metal frameworks in fixed and implant prosthodontics. The type of zirconia used in dentistry is yttria tetragonal zirconia polycrystal (Y-TZP). Y-TZP is a monophase ceramic material formed by directly sintering crystals together without any type of intervening matrix to form a dense, polycrystalline structure. Yttria is added to zirconia to stabilize and maintain the material's physical properties at lower temperatures than would otherwise occur without yttria.

The flexural strength of zirconia oxide materials has been reported to be 900 to 1100 MPa.[48] There are three main types of zirconia used in clinical dentistry: fully sintered or Hot Isostatic Pressing (HIP); partially sintered zirconia; and non-sintered or "green state" zirconia. The latter two types are softer than HIP zirconia and more cost efficient to mill. After milling, zirconia frameworks are sintered in furnaces at 1350 to 1500°C where the final shapes, strengths, and physical properties are achieved. Partially sintered zirconia frameworks are milled 20% to 25% larger than the actual frameworks to allow for shrinkage during the sintering process.[49]

Larsson and Vult von Steyern reported the results of a clinical study that compared clinical performances of 2- to 5-unit implant-supported, all-ceramic restorations fabricated with two zirconia systems.[50] They concluded that all-ceramic, implant-supported fixed dental prostheses of two to five units were reasonable treatment alternatives. One system in their study exhibited an unacceptable amount of porcelain veneer fractures and was not recommended for the type of treatment evaluated in their trial.

Guess et al performed a literature review for citations published from 1990 through 2010 regarding zirconia in clinical dentistry.[51] They reported high biocompatibility, low bacterial surface adhesion, and favorable chemical properties of zirconia ceramics. Zirconia, stabilized with yttrium oxide, exhibited high flexural strength and fracture toughness. Preliminary clinical data confirmed high stability of zirconia abutments and also as framework material for implant crowns and fixed dental prostheses. Zirconia abutment or framework damage was rarely reported; however, as also noted by Larsson and Vult von Steyern, porcelain veneer fractures were common technical complications in implant-supported zirconia restorations. Porcelain veneer failures were thought to be related to differences in coefficients of thermal expansion between core and veneering porcelains, and their respective processing techniques. Guess et al[51] concluded that since clinical long-term data were missing, clinicians should proceed with caution relative to designing extensive implant-borne zirconia frameworks.

Accuracy of framework/implant fit has long been a topic of discussion. Guichet et al, in a laboratory study, reported an average marginal opening of 46.7 μm for screw- and cement-retained fixed dental prostheses.[52] Upon screw tightening, marginal openings for the screw-retained group decreased an average of 65% to an average of 16.5 μm. The prostheses in both groups were made after master casts had been verified; however, it should be noted that there were no significant differences in marginal adaptation between the groups prior to screw tightening or cementation. Screw tightening did result in a statistically significant difference. Guichet et al noted that their results compared favorably with the results of other studies.[53,54] They further noted that the fit of one-piece castings continues to be controversial when passive fit is a criterion for clinical acceptability. The effects of soldering, as compared to one-piece castings, according to the authors, merits continued study.

One-piece casting procedures have produced stable and relatively homogeneous frameworks.[55] Cast metal frameworks are subject to expansion and contraction that may result in porosity and/or distortion of individual castings. Wichmann and Tschernitschek reported the results of a clinical study where almost one third of the evaluated castings exhibited casting defects.[56] Multiple studies have reported that CAD/CAM Ti frameworks achieve implant/framework fits superior to those obtained with cast metal frameworks.[57-60] In a laboratory study, Al-Fadda et al reported that CAD/CAM milled frameworks demonstrated significantly less error when compared to cast frameworks (33.7 μm vs. 49.2 μm) in the vertical axis; differences in the horizontal plane were 56 μm and 85 μm, respectively.[59]

In general, most clinical studies regarding implant prosthodontics have reported on implant and prosthesis cumulative survival rates (CSRs). Framework design has not been extensively discussed or reviewed. Interest in CAD/CAM technology for implant restorations has been increasing for multiple reasons, including that frameworks and abutments may be machined from solid blanks of material (Fig 8). Blanks are more homogeneous than conventional castings; physical properties are generally better. CAD/CAM technologies have eliminated conventional waxing, casting, and finishing procedures, along with the inaccuracies associated with these procedures. CAD/CAM frameworks produced commercially are generally less expensive for clinicians than cast metal frameworks, as they do not contain noble metals. CAD/CAM frameworks may be designed completely with computer software programs (Fig 9), or they may be waxed to certain specifications by dental technicians, scanned, and then milled in a procedure called “copy milling.” The latter frameworks generally will not result in the decreased costs associated with CAD frameworks designed in CAD, as significant labor costs will be incurred in developing the wax/resin framework patterns (Figs 10 and 11).

Figure 8 Titanium alloy blank prior to placement into milling machine for milling a CAD/CAM implant framework (Biomet 3i, Palm Beach Gardens, FL).

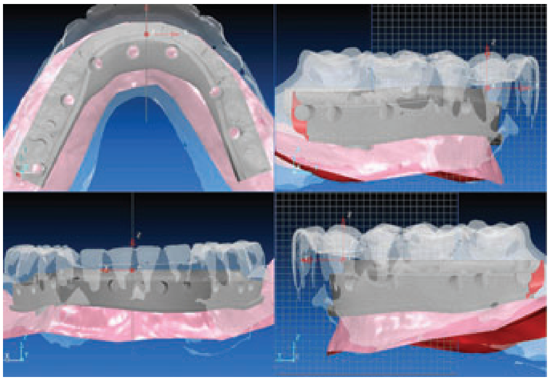

Figure 9 Representative set of JPEG images of a proposed design for a CAD/CAM mandibular implant framework/hybrid prosthesis. Note the “ghosted” images of the teeth. These types of images are sent to clinicians and laboratory technicians for input prior to milling

Based on the above studies, differences in accuracy of fit (CAD/CAM vs. cast frameworks) have been statistically significant; however, clinical significance has not been established.

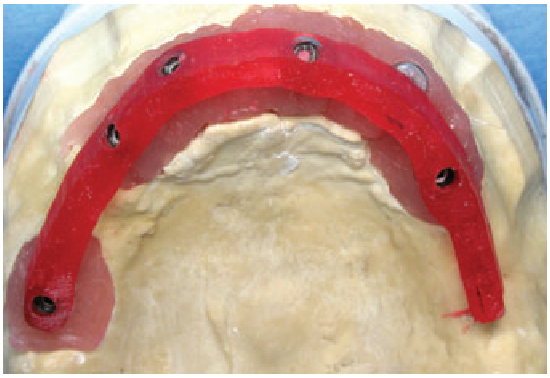

Figure 10 Laboratory occlusal image of a resin pattern, fabricated by a dental laboratory technician with specific contours, in preparation for a copy-milled CAD/CAM framework (North Shore Dental Laboratories, Lynn, MA).

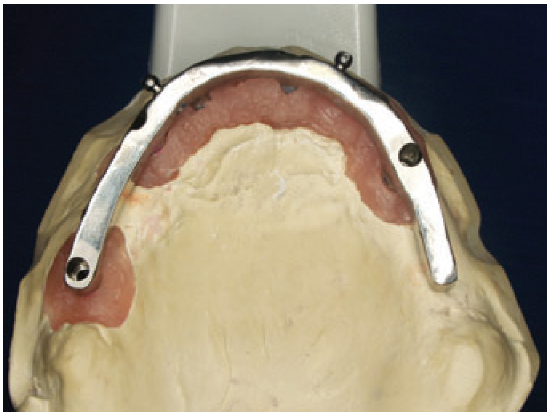

Figure 11 Laboratory occlusal image of the milled titanium alloy framework consistent with the resin pattern in Figure 10 (North Shore Dental Laboratories).

Some clinicians may not wish to use soldered frameworks as opposed to one-piece castings or milled frameworks. Specific clinical guidelines relative to framework fabrication have not been established. Among the factors clinicians may consider in fabricating fixed implant frameworks are: biocompatibility/type of alloy/type of ceramic, CAD/CAM (digital/copy mill), lost-wax technique, and expense. The authors of this article prefer to use CAD/CAM milled frameworks due to the accuracy of fit, biocompatibility/homogeneity of milled Ti alloy blanks, and decreased costs.

Design considerations

Implant frameworks must be rigid to support fixed prostheses. Frameworks with cantilevered, freestanding segments have areas of high stress at or distal to the posterior abutments, and may compromise the structural integrity of inadequately designed frameworks.[5] Framework fracture may be avoided with optimal, mechanically designed frameworks. I-beam designs have been proposed to strengthen cantilevered portions of frameworks.[61] Taylor stated that cast alloy frameworks must have at least 3 mm of vertical bulk to provide sufficient rigidity to frameworks.[62] Rasmussen stated that I-beam-designed frameworks maximized resistance to occlusal loading and minimized permanent deformation under stress.[63] I-beams also provide rigidity and strength to frameworks with minimal increased bulk and weight (Fig 12). Rasmussen published his results in a clinical report where he incorporated I-beam framework designs into 35 prostheses, followed those patients for 3 years, and reported zero prosthetic failures.

Figure 12 CAD implant framework with a modified I-bar design. The apical buccal and lingual portions of the framework were designed for use as finish lines for the denture base portion of the hybrid prosthesis.

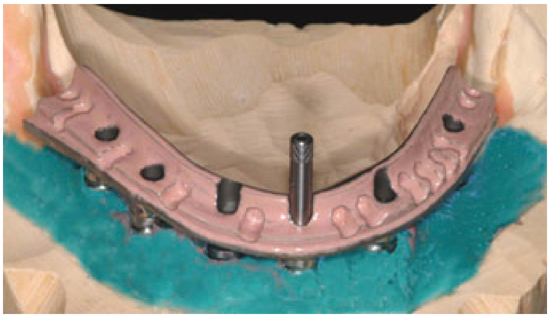

Figure 13 Example of a CAD/CAM milled framework with the L-beam design. Teeth are supported apically by the horizontal component of the L-beam design. The framework is designed to provide adequate support for the artificial teeth and denture base to minimize the risks of denture tooth/base fracture.

Staab and Stewart evaluated two parameters regarding implant framework design (L, I, elliptical, and oval): beam deflection and maximum normal stress.[64] They noted that each of the tested designs could be viable clinically. They also reported that the I-beam design deflected less and experienced the smallest maximum normal stress of the tested designs. Elliptical designs deflected the most. The L design experienced the largest normal stress. Staab and Stewart noted the effectiveness of any framework design clinically could not be easily identified from a simple, static analysis; they also noted that the numerical differences they observed among the different designs were based on conditions that they decided upon for their experimental evaluation. Staab and Stewart[64] basically concurred with Cox and Zarb[61] and Rasmussen,[63] but did not propose that only I-beam configurations strengthened framework cantilevered segments.

Von Gonten et al stated that relative to framework design, consideration should be given to limit the amount of acrylic resin to retain artificial denture teeth.[65] Assuming rigid fixation to implants, areas of high stress concentrations in implant frameworks were focused at or just distal to the most posterior abutments in an arch, and would likely compromise the structural integrity of incorrectly designed frameworks.[63] Stress concentrations in these areas can be considerably greater than the mean applied force. Effective distribution of applied forces during mastication and clenching may be diminished by cantilevered segments deforming under stress. The worst-case scenario would be metal fatigue and fracture. Framework fractures may be minimized with proper design considerations.

Von Gonten et al described the fabrication of a mandibular fixed implant-supported framework with a more extensive cast alloy framework than was found in frameworks designed prior to 1995.[65] Their design consisted of an L-beam with extended vertical wall height lingually. The authors speculated that this provided increased resistance to cantilever stress and would resist fracture better than frameworks designed as I-beams (Fig 13). Von Gonten et al stated that this design was consistent with desirable physical properties, was readily maintainable by patients, and could be produced with available methods and materials. Von Gonten et al acknowledged that the L-beam design required significantly more alloy (12–14 pennyweights) and would be significantly more expensive than frameworks fabricated with I-beam designs. Unfortunately, the authors did not provide scientific evidence that the L-beam design resulted in more successful implant frameworks.

It is interesting to note that framework design characteristics have not been extensively reviewed or described. Sadowsky, in a 1997 comprehensive review article, described numerous characteristics of frameworks relative to adaptation to soft tissues, cleansibility, anterior/posterior (A/P) spread, and cantilever length, but was unable to cite definitive laboratory studies where variables were evaluated and conclusions drawn that would be helpful to clinicians designing implant frameworks.[66]

A/P spread has been discussed by several authors.[67,68] It was defined by English as the distance between the line connecting the two most distal implants and the center of the implant most distant to that line.[67] The A/P spread provides a macroscopic measure of the geometric distribution of the implants. Cantilever length and A/P spread are essential factors regarding distribution of occlusal loads. Some authors have suggested that cantilever lengths of 1.5 and A/P spreads of 2 be guides for maximum allowable cantilever lengths.[67,68] A cantilever length/A/P spread ratio of 2 was determined to be optimal by choosing implant forces equal to twice the applied loads as the failure criteria.[69] Cantilever lengths of 1.5 times the A/P spread were determined empirically for prostheses supported by five implants after considering clinical conditions that might biomechanically compromise the biologic and/or prosthetic outcomes of clinical cases.[69] Beumer et al recommended a minimum of six implants with an A/P spread of at least 20 mm and sufficient bone in the second premolar areas to support 10 mm implants.[70] English recommended cantilever lengths be 1.5 times the A/P spread, but shorter in poor quality bone.[67] Due to bending moments, the presence of load-bearing cantilevers increase forces distributed to implants, possibly up to two or three times the applied loads on a single implant.[71] McAlarney and Stavropoulos observed that cantilever lengths seen clinically were often lower than those deemed optimal by clinicians for restoration of structure, function, and esthetics.[69]

The rationale for cantilever length

McAlarney and Stavropoulos investigated possible relationships between calculated clinical cantilever length variables that included number and distribution of implants, arch placement, and clinically optimal cantilevers. For a set number of implants, the relationship between calculated cantilever length and A/P spread was linear.[70] The sum of the lengths on both sides versus prosthesis length between the most distal implants was linear, regardless of the number of implants. Predicted clinical success was defined as calculated length greater than the clinicians' optimal length. Satisfaction rates were 100%, 56%, 33%, 8%, and 0% for cases supported by 8 and 7, 6, 5, 4, and 3 implants (44% overall), respectively. Ninety-eight percent of cases with A/P spreads greater than 11.1 mm were satisfactory. McAlarney and Stavropoulos concluded that in 98% of all clinical cases studied with an A/P spread greater than 11.1 mm, the maximum cantilever length calculated through the mathematical model was greater than the cantilever length desired by the clinicians restoring the cases; the calculated maximum permissible cantilever lengths as calculated varied linearly with the A/P spread.

McAlarney and Stavropoulos also investigated the ratio that existed between cantilever length (CL) and the A/P spread, as this ratio is often used as an indication of CL in implant-supported prostheses.[69] They reported that although there was a trend of increasing CL with increasing AP spread, indiscriminate use of a single CL:AP ratio as an indication for cantilevers may not be prudent, because CL is also a function of the number of implants and the distribution of implants between the most anterior and posterior implants. Also, previously reported CL:AP ratios may be too high for different clinical situations. They reported that a CL:AP spread ratio of 2 was too great for all the cases studied, and that a ratio of 1.5 was too great for all cases except for six implant cases. It was interesting to note that the ratios varied by a factor greater than 3.

A/P spread and the "All-on-Four" protocol

Implant treatment in edentulous maxillae may be quite challenging and more difficult compared to mandibular implant treatment as atrophic, edentulous maxillae generally consist of less-dense bone; several anatomic areas also preclude implant placement (nasal cavity, maxillary sinus).[72,73] Malo et al introduced a concept they termed "All on Four." This protocol called for placement of four maxillary implants: two vertical and two distally tilted implants, placed parallel to the anterior walls of the maxillary sinus (Fig 14).[74] One of the tenets of this treatment concept was that patients who were edentulous for many years usually warranted bone grafting in the maxillary sinus to compensate for minimal alveolar bone volumes

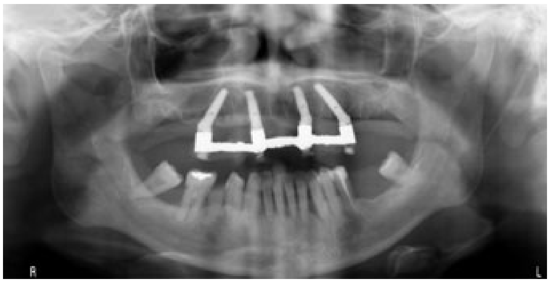

Figure 14 Panoramic radiograph of a patient treated with the "All-on-4" protocol. The two distal implants were placed parallel to the anterior wall of the maxillary sinus.

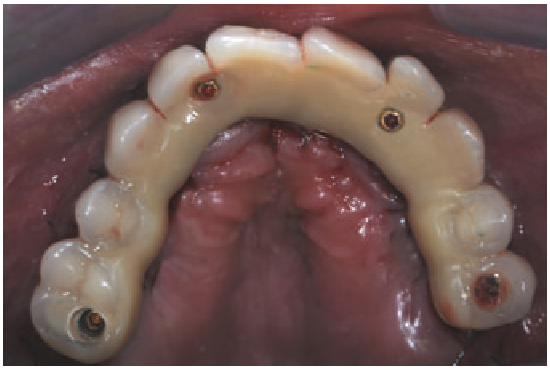

Figure 15 Clinical occlusal view of the prosthesis in Figure 14. The tilts of the distal implants were corrected with angled abutments. The A/P spread was significantly increased if compared to the A/P spread of four vertically placed implants.

posteriorly. For these patients to be treated with dental implants, sinus grafting would be warranted, and introduced additional surgical procedures, morbidity, and costs. Malo et al proposed reconstructing edentulous maxillary patients with a total of four implants: two anterior implants vertically placed and two posterior tilted implants where the tilted implants were placed anterior and parallel to the anterior sinus walls. The posterior implants required angled abutments for the prosthetic procedures (Fig 15). This specific implant arrangement provided for consistently large A/P spreads.

A recent (2010) publication detailing the "All-on-4" protocol reported the CSR for maxillary implants was 98.36%; mandibular implants was 99.73%.[75] Patients were followed for 4 to 59 months. Sixty-one maxillary prostheses and 93 mandibular prostheses were placed and followed; at the time the study results were published, the prosthetic CSR was 86%. The authors reported no differences in marginal bone loss between axial and tilted implants.

Guidelines for implant-retained hybrid frameworks

1. *Frameworks must be fabricated from materials and protocols that allow passive and accurate fit between frameworks and implants and/or abutments*. CAD/CAM fabricated frameworks generally provide better, more accurate fit than do cast frameworks.[57-60] Milled frameworks from solid blanks of Ti or Ti alloys are homogeneous; defects within CAD/CAM frameworks are minimal when compared to defects noted within cast frameworks.[57,58]

2. *Frameworks must be designed to resist tensile and compressive forces associated with mastication and parafunctional habits*. Frameworks need to be of adequate thickness buccally/lingually, and vertically. Thickness will depend on the type of metal and fabrication process used for each specific framework, the number and length of implants, the type of supporting bone, and the opposing occlusion. Carr and Stewart recommended cast bars be approximately 7 mm tall and 6 mm wide; one-piece castings were imprecise and inaccurate when evaluated for passive fit.[76] CAD/CAM milled frameworks may have slightly smaller dimensions. One manufacturer (Biomet 3i, Palm Beach Gardens, FL) only specifies that the minimum vertical height for milled bars is 2.5 mm. Two other manufacturers' websites (Nobel Biocare; Cagenix) did not contain any information relative to thickness for their bars. I-beam designs may be the best designs for implant-retained hybrid prostheses.[61,63,64]

3. *Framework design has evolved into a series of clinical and laboratory procedures that incorporate principles of fixed and removable prosthodontics; prostheses are more successful if frameworks are designed consistent with predetermined tooth positions*. Frameworks must be designed with adequate space (1.5 to 2 mm) for prosthetic materials: acrylic resin/composite resin/reinforced polymeric materials.[77] Retentive elements for denture base materials should be designed as integral parts of implant frameworks. Adequate thickness is necessary to minimize the potential for denture base fracture. Acrylic resin retention may be accomplished with nailhead retentive elements, retentive loops, or undercut areas randomly placed throughout frameworks. Retentive elements should be placed such that they will not interfere with tooth placement. Junctions of acrylic resin and metal finish lines should have retentive undercuts.[77] Resins are mechanically attached to metal frameworks; well-developed and distinct finish lines minimize stain and seepage of intraoral fluids into and around the resin/metal junction. Malodors may be caused by deposits at the resin/metal interface; separation between resin and metal may eventually lead to deterioration of denture bases.

There has been considerable research relative to acrylic resin retention in removable partial prosthodontics. In a laboratory study (80 chrome/cobalt frameworks), Lee et al concluded that significantly increased force was required to separate "primed" acrylic resin from RPD metal frameworks when compared to unprimed specimens.[78] Forces required to dislodge acrylic resin from RPD frameworks decreased in the following order: primed metal with beads (highest) > primed mesh > primed lattice > smooth metal plate (lowest). Primed latticework acrylic resin retention was significantly less retentive than the other three primed designs. In a similar study, Bulbul and Kesim reported that shear bond strengths (SBS) varied according to metal type, metal primer, and acrylic resin.[79] The SBS was highest between base metal and heat-polymerized resin with metal primer. SBS between noble metal and acrylic resin, for all control groups, was the lowest (0.4 ± 0.07 MPa) ($p < 0.001$). For Ti, the highest SBS was observed for Meta Fast primed specimens; the lowest for the control group. For base metal, the highest SBS was for Metal Primer; the lowest for the control group. For the noble metal group, the highest SBS was for Alloy Primer; the lowest for the control group ($p < 0.001$). Bulbul and Kesim concluded that metal primers were associated with increased adhesive bonding between acrylic resins and the metal alloys tested. Bonding values were higher for resin to base metal alloy RPDs when compared to noble and Ti alloys.

Clinicians must determine the appropriate location of the artificial teeth prior to designing frameworks. In edentulous patients, waxed denture prostheses must be constructed so that they may be imaged/scanned prior to proceeding with framework design. Matrices or facial cores are not needed for scanning CAD/CAM frameworks; however, they are helpful for technicians setting artificial teeth onto the frameworks prior to the framework/wax try-in.

4. *Cantilever extensions are dependent on: type of metal used in the frameworks, number and location of implants.* Base metal alloys flex less than noble alloy frameworks. Frameworks supported by three implants, with an A/P spread equivalent in millimeters to frameworks supported by six implants with the same A/P spread, should be designed with smaller cantilevers when compared to the six-implant-supported framework. Cantilever extensions may extend up to 1.5 of the A/P spread. Cantilevers may also be shortened depending on the above factors.

Conclusions

This article presented a review of current and past literature regarding implant-retained frameworks for full-arch, hybrid restorations. Benefits, limitations, and complications associated with fixed implant prostheses were discussed including the relative inaccuracy of casting/implant fit and improved accuracies noted with CAD/CAM framework/implant fit; cantilever extensions that were initially designed arbitrarily versus frameworks designed relative to the A/P implant spread; and the mechanical properties associated with implant frameworks including I- and L-beam designs. Guidelines were proposed for use by clinicians and laboratory technicians in designing implant-retained frameworks. Further clinical and laboratory research continues to be warranted to test the efficacy of the proposed guidelines.

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