Perspectives in Prosthodontics: 1970-2010

In Celebration of the 40th Anniversary of the American College of Prosthodontists

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Foreword

The 40th anniversary of the American College of Prosthodontists is an opportunity to celebrate prosthodontic innovation. The last 4 decades have seen seismic changes in diagnostic methodologies, restorative care options, material science, application of technology, and the use of evidence-based practice as the foundation for treatment planning. As we enter the Age of Information, Malcolm Gladwell, keynote speaker for the 40th Annual Session in Orlando, Florida, has noted, "The key to good decision making is not knowledge. It is understanding. We are swimming in the former. We are desperately lacking in the latter." As master diagnosticians and endpoint providers, prosthodontists have become leaders in adopting an evidence-based approach to assess new strategies in the delivery of services to our patients. The process, however, has required a renaissance of thinking and breaking down old, well established models and principles as we assess quantum changes in such fields as implant dentistry, maxillofacial prosthetics, all-ceramic restorations and digital applications.

New understanding must overcome the inertia fueled by entrenched ideas. The long accepted dental model has not been easily discarded. Albrektsson et al[1] has underscored this tendency in his editorial, "A Requiem for the Periodontal Ligament Revisited," that a clinician's lack of willingness to accept the fundamental differences between an evolved attachment mechanism for a tooth and the implant-bone complex, has led to obsolete etiological explanations for peri-implantitis. However, evidence has helped to dissolve revered shibboleths. For example, Blanes[2] has reported in a systematic review that crown-to-implant ratios of 2:1 do not influence crestal bone loss or mechanical complications, unlike natural teeth. Also, 5-year clinical trials[3, 4] and in vitro studies[5, 6] have demonstrated that tilted implants up to 45 degrees have a high survival rate and biomechanically transmit a reduction of stresses in the peri-implant bone, contrary to orthodox thinking.

Arguably, implants have led to the most dramatic improvements in quality of life in the sphere of maxillofacial prosthetics. But early on, placing implants in irradiated bone was considered too risky. Mindsets were still mired in the 1978 Harvard Conference[7] detailing the limitations of blade endosteal implants. However, with careful management of the remaining hard and soft tissues and later the use of hyberbaric oxygen, endosseous treatment philosophy changed.

Now implant-retained prostheses for the craniofacial cancer patient have become *de rigueur*. In fact, Colella et al, in a systematic review[8], have reported respectable implant survival rates with both pre- and post-implantation radiation therapy. More recently, the field maxillofacial prosthetics has been slow to embrace advanced digital technologies, despite the promise of more accurate modeling. New paradigms are lagging in academic curricula and the clinical setting.

The use of all-ceramic crowns for posterior restorations has been met with suspicion by metal-ceramic crown enthusiasts. However, Pjetursson et al[9], in a systematic review of 5-year survival of densely sintered alumina crowns and reinforced glass-ceramic crowns, found no difference in complication rates compared to metal-ceramic crowns. Long-standing flexural strength concerns with all-ceramic restorations have been countered with the introduction of Y-TZP ceramic. However, until established PFM protocols were changed for both cooling parameters of veneering ceramics and framework design for zirconium-based restorations, long-term clinical success was not achievable.[10] The replacement of traditional techniques for fabrication of all-ceramic restorations also has been resisted, but CAD/CAM-generated all-ceramic molar crowns have been reported with a survival rate of 94.6% up to 7 years.[11] Using this new technology, optimized processing parameters prevent the formation of microstructural defects.[12] Finally, the prospect of digital impressions completely replacing traditional intraoral impressions is still an anathema to many prosthodontists. But, da Costa et al[13], have demonstrated no differences in the marginal gap with inlays made with an optical impression or with an elastomeric impression material. Advances in science and technology continue to offer viable alternatives in patient care with the prospect of eclipsing the precision and reliability of present procedures.

The articles written by the contributors to this anniversary retrospective well chronicle the advances in patient care since the inception of the American College of Prosthodontists. The next 40 years will surely bring exponential change to the entire area of prosthodontics and how we embrace those changes will define our specialty. It is apparent that intransigence and premature adoption are two sides of the same coin. An immutable question remains when considering change: Is there evidence to show that new technologies enhance the prospect of meeting patient's needs with predictable, enduring, and affordable treatment?

— Steven J. Sadowsky, DDS, FACP

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Chapter 1 *The Implant Restoration of the Edentulous Patient*

Steven J. Sadowsky, DDS, FACP

Introduction

The 1980s marked a watershed moment in prosthodontics with the introduction of the osseointegration concept to North America, irrevocably changing rehabilitative approaches for the edentulous patient. Although the *ad modum* Branemark design has achieved unparalleled longitudinal implant success and prosthetic stability, [1] there has been over the last three decades an emergence of a new set of outcomes measures related to quality of life concerns.[2, 3] These data have led to permutations of the original prototype and need for algorithms in the diagnosis and differential treatment planning for the edentate. Complete denture principles continue to be the foundation for developing the restorative blueprint.[4] Objective determinants such as hard and soft tissue quality/quantity of bone, jaw anatomy, morphology and class, antagonist dentition and loading forces will aid in the choice of prosthesis.[5] Subjective determinants such as the patient's expectations of retention security, esthetics, hygiene access, maintenance and costs will also aid in selecting the appropriate design.[6]

Implant Restoration of the Edentulous Mandible

In the latter part of the 1980s, a 2-implant overdenture design was introduced and found to be efficacious, for both the solitary anchor and bar anchorage system.[7, 8] In 2002, The McGill Consensus established the 2-implant mandibular overdenture as the "first choice standard of care" for edentulous patients.[9] `In fact, a 10-year clinical trial demonstrated no differences in clinical or radiographic indices, maintenance, or patient satisfaction with a 2- or 4-implant overdenture design.[10] However, Fitzpatrick [11], in a systematic review of the literature, countered the McGill consensus by noting that considering dentist- and patient-mediated outcomes, a universal intervention for the edentulous mandible has not been demonstrated. The following examples make this point. A single symphyseal implant design for geriatric patients has been reported to achieve high implant survival and patient satisfaction, with limited surgical and financial exposure.[12, 13] When the residual height of the anterior mandible precludes the use of implants with at least a length of 8.5 mm and a width of 3.5 mm, a 4-implant array is recommended to maximize implant survival.[14, 15] Furthermore, the decision to provide an overdenture design or a fixed implant complete denture is contingent on a myriad of factors. Patients with marked posterior residual ridge resorption[16, 17], tapered mandibular arch form[18], TMD[19], or combination syndrome[20] may benefit more from a fixed rather than a removable prosthesis. On the other hand, patients with off-ridge relations[5], concerns regarding facial or dental esthetics, [21] hygiene access considerations, [22] or cost containment priorities[23] may be best treated with an overdenture. However, long-term costs of overdentures due to maintenance may surpass the initial advantage of lower upfront fees compared to a fixed prosthesis.[24-26] That being said, the aftercare burden investigations on overdentures have been focused on solitary anchors or the Dolder bar design. Krennmair et al[27] and Dudic et al[28] have independently demonstrated lower mechanical complications with a milled bar substructure. Additionally, the computer numeric controlled (CNC) process has been shown to offer superior fit to the conventional lost wax technique (13-15 microns vs. 43-180 microns) and may minimize biomechanical complications. [29, 30]

More recent design developments in fixed prosthetic designs using implant-supported fixed metal-ceramic reconstructions[31] and CAD/CAM milled titanium framework with all-ceramic zirconium oxide crowns, [32] may offer improved aesthetics, phonetics and casting accuracy. However, long-term studies are not available to assess their benefit/cost calculus. While the application of ceramic restorative materials resist progressive wear often seen in denture teeth,[33] fracture may pose a significant aftercare burden, especially if the prosthesis is not readily retrievable.

The effectiveness of immediately loading the edentulous mandible, within 1 week, [34] has been reported in the literature over the last decade. However, despite the

advantages of immediate restoration of function and decreased patient treatment visits, [35] controversy persists whether the regimen improves patient satisfaction and cost effectiveness.[36] In fact, increased complications have been reported when an immediate loading approach was used for both removable and fixed designs, compared to the conventional time-to-loading protocol.[37, 38] Notwithstanding these considerations, patients may present with conditions which would optimally be treated with an immediate load protocol such as transitioning from a dentulous to an edentulous state,[39] compromised anatomy,[40] somatogenic gagging [41] or psychogenic disabilities. Careful patient selection will maximize successful outcomes. Host-related factors which may compromise either implant stability or wound healing capacity should preclude using this treatment regimen.[42] These include metabolic diseases, heavy smoking, parafunction, bone augmentation to implant site, drug/alcohol abuse, antiblastic chemotherapy or steroids.[43-46] Above all, immediate load protocols require primary stability (e.g. 45 Ncm insertion torque value, 54 Implant Stability Quotient using resonance frequency analysis)[47-49] and low surgical trauma for predictable osseointegration.

Implant Restoration of the Edentulous Maxilla

The maxillary fixed implant complete denture has been documented with high 15-year implant survival rates, [50] but it was soon evident that this prototypic design again did not have universal application. To address such patient needs as unfavorable maxillomandibular relations, concerns regarding facial and dental esthetics, speech competency, hygiene access and cost containment issues, the maxillary overdenture design evolved. In fact, patients who reported chronic problems with their maxillary dentures, preferred a long-bar overdenture design to a fixed implant complete denture by more than 2 to 1.[51] But historically, this treatment modality has suffered from relatively high implant failure [52-54] and a high aftercare burden[26] due to reduced bone quality and quantity, divergent implant axes, off-set positioning of the teeth and generally higher loading forces.[55] Moreover, this modality is characterized by a limited portfolio of strong hierarchical evidence.[56] However, specific design considerations have been proposed to improve the maxillary overdenture implant survival and complication rates.

While there are no definite guidelines for the number of implants, there appears to be a consensus that at least 4 implants are favorable for a palateless design.[57-59] The recommended minimum length for textured implants is 10 mm[60], although Ferrigno et al, [61] found in a 10-year prospective study a 93% implant survival rate for maxillary overdentures supported by 12 mm long implants and a 91.6% survival rate when supported by 10 mm long implants. Heterogeneity in research methodology has plagued an objective assessment of whether an unsplinted or splinted anchorage

system is preferred from the standpoint of mean bone loss. The decision to select the unsplinted design may be patient- and clinician-mediated as it requires less space, is easier to clean, is more economical and is simpler to reline than a Dolder bar substructure.[55] However, longitudinal studies have shown the milled-bar design to be superior to the solitary anchor or Dolder bar system for both implant survival and mechanical complications.[27, 28, 61-63] In patients with limited residual alveolar resorption, a premium on natural crown contours, and adequate financial wherewithal; a full arch metal ceramic reconstruction may be an appropriate prosthetic alternative. Five-year cumulative implant survival with this design has been reported to be 98.5%, when an average of 7.5 implants of 14.5 mm length has been immediately installed, with a maximum cantilever length of no more than 10-12 mm.[64] There is little evidence that implant survival or success is affected directly by prosthesis type based on current designs studied for at least 5 years. Prosthesis maintenance does appear to vary with different prosthesis designs.[65]

Only limited data are available on immediate load on the maxilla and is not sufficiently supported scientifically.[66] However, Romanos et al[67] completed a 5-year study in 2009, on immediate functional loading in the edentulous maxilla, using a progressive thread design and platform switching, demonstrating a 96.6% implant survival. Primary stability, cross-arch stabilization and a soft diet were emphasized in the protocol. The application of new implant surface treatments such as nanometer-scale calcium phosphate may hold promise as short-term effectiveness in immediate load scenarios has been demonstrated.[68]

Despite the lack of long-term studies of sufficient methodological rigor, there has been a broad interest in both the Teeth in a Day protocol[69] and the All-on-Four[70] concept for immediately restoring the edentulous maxilla. The application of computer generated diagnostic and treatment regimens have expanded the application of the immediate load protocol.[71, 72] The next decade will offer a substantive perspective on the efficacy of these digital innovations.

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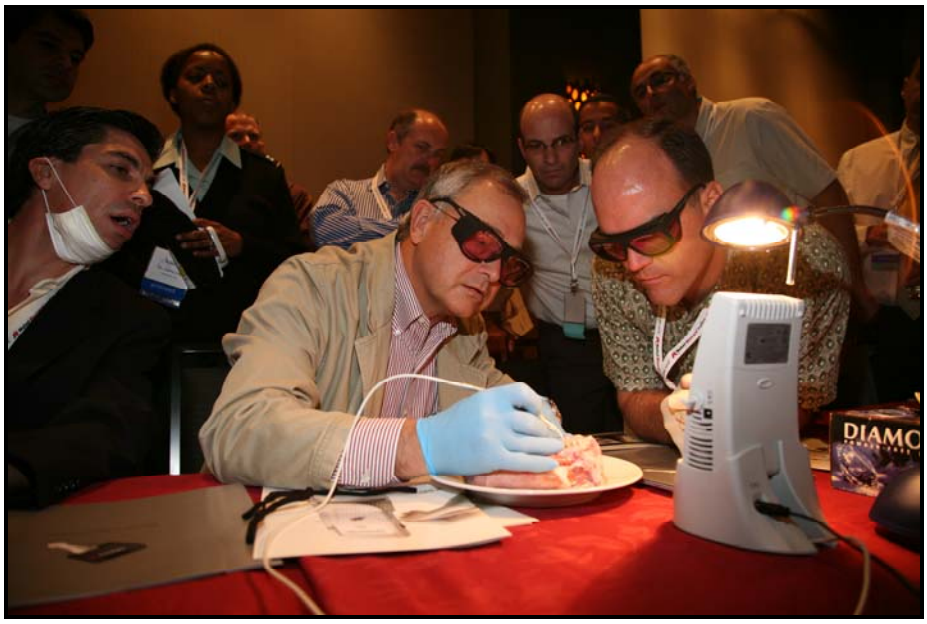

Chapter 2 *The Development of Dental Implant Therapy for Partial Edentulism*

Lyndon F. Cooper, DDS, PhD

Partial Edentulism, its Scope and Historical Outcomes of Treatment

The current status of partial edentulism in the United States may be reflected by information gathered in the Third National health and Nutrition Examination Survey (NHANES III) that estimated the prevalence and distribution of tooth retention and tooth loss among adults over the age of 18. From 1988 to 1991, approximately 1/3 of the population had retained all of their teeth. However, the mean number of teeth was 23.5 for dentate persons. These people most commonly retained all of their anterior teeth. This indicates that there exist tens of millions of partially dentate individuals in the US and that a large proportion of these individuals are missing posterior teeth (Marcus et al 1996). This finding reiterates that, based upon a survey of a regional laboratory production, the majority of removable partial dentures were for Kennedy class I and class II scenarios(Curtis et al,1992). When the prevalence of tooth loss was examined in Europe, Muller et al (2008) also concluded that the aging population displayed reduced dentition in need of prosthodontic treatment. They concluded that the World Health Organization goal of retention of at least 20 teeth at the age of 80 years was not yet universally attained.

The challenge of restoring function and esthetics to the partially dentate patient has historically been met using removable partial dentures. As late as 2006, a survey of US dental schools confirmed universality of training students in removable partial denture techniques, including the use of border molding of impressions and the use of semi-adjustable articulators, as well as the process of surveying casts. Over 80 percent of schools maintained a set number of clinical requirements for removable partial dentures and this suggests that during the current period, dentistry includes the treatment of partial edentulism using removable partial dentures (Petropolis and Rashidi, 2006).

Despite the education of dentists in the application and technique of removable partial dentures, there exist defined limitations in the treatment of partial edentulism using removable partial dentures. Patient reported outcomes have revealed that there is low acceptance of esthetics and function (chewing), and that patients have dissatisfaction with retention and comfort. Hummel (2002) concluded that for a large population of individuals treated with removable partial dentures, only 1/3 were free of significant defects that included movement (lifting upon unilateral or bilateral force) and loss of retention as indicated by dislodging upon moderate opening of the mouth. The outcomes of tooth replacement using removable partial dentures have also been questioned. A retrospective evaluation of abutment tooth survival with a removable partial dentures had the poorest 10-year survival rate (Aquilino et al 2001). More recently, Miyamoto et al (2007) revealed that among all treatments of teeth, removable partial abutments experienced the highest failure rate.

The treatment of partial edentulism involving removable partial dentures remains a large part of dental therapy. This is despite evidence that the treatment is poorly accepted by patients and there are biological consequences that negatively affect the support of alveolar bone and adjacent teeth. The prescription of dental implants to improve the major limitations of lack of stability, retention and long-term success of removable partial dentures has a history in dentistry of over 50 years.

Initial Efforts to Replace Removable Partial Dentures Using a Dental Implant Concept

In the 1960s and 1970s, clinicians began to explore the possibility of replacing removable partial dentures with implant-supported fixed dental prostheses. While subperiosteal implants were being utilized for the edentulous patient, blade implants were designed specifically for placement in the posterior mandibular alveolar ridge for support of fixed dental prostheses. There is little

clinical data to consider when reviewing this treatment strategy. However, in 1987, the Veterans Administration Cooperative Dental Implant Study was introduced and in 1989, the success of implant-supported fixed dental prosthesis reported a 5- year success rate a 84.2% and compared favorably to a reported 74% success rate for the removable partial dentures. It must be noted that different radiographic criteria for bone loss were utilized in determining success than is applied today. Importantly, when patient satisfaction was considered after 5 years, some increased satisfaction was measured for patients treated using implants. These early efforts to improve the treatment of the partially dentate patient by avoiding a removable partial denture met with some success. Early predictions included that blade implants and the anatomic advantages for placement in the narrow mandibular ridge would not be displaced by osseointegrated implants (Babbush1986). However, the biologic reality and clinical longevity of the blade implant itself required careful evaluation. Smithloff and Fritz (1987) indicated that only 50% of blade implants evaluated over 15 years were free of bone loss, bleeding on probing or radiolucency. The 1988 consensus conference on dental implants included a discussion of the merits of osseointegrated endosseous dental implants and so called "fibro-osteal" blade implants (Weiss, 1988). With little clinical data to support the approach for blade implants, the ultimate result of the discussions that occurred during that consensus conference included the adoption of success criteria which ultimately excluded the use of blade implants from mainstream use in support of dental prostheses.

Thus, in the mid-1980s, the demand for rehabilitation of the partially dentate patient using alternatives to removable prostheses was growing. Yet, the profession lacked sufficient alternatives to the removable partial denture that were supported by evidence. The advances that were promised by osseointegrated endosseous dental implants were emerging in well documented, retrospective and prospective cohort studies involving edentulous patients. The translation of this technology to the partially dentate patient was needed.

The Establishment of Osseointegrated Dental Implant Therapy for Treatment of Partial Edentulism

The introduction of osseointegrated dental implants has had a profound effect on Prosthodontics. Beyond its biologic and clinical advantages, its introduction changed the process of choosing one or another technique based on evidence. While the initial studies by the Branemark team were cohort studies and not randomized controlled studies involving a wide range of patient outcomes, the data concerning implant survival supported the use of implants in the

parasymphyseal mandible of edentulous patients. By the mid-1980's the original reports of Adell (1981) and the replicate studies of Zarb (1983) were well disseminated. Endosseous implants supporting cross-arch splinted dental prostheses in edentulous subjects were accepted. The transition of this technology from the edentate patient to the dentate patient required additional consideration.

The application of osseointegrated implants for partial edentulism was introduced in several papers during the late 1980s. Jemt et al (1989) reported on treatment of 244 patient between 1968 and 1988. They demonstrated for 876 Branemark implants the loss of 24 fixtures (3%) with a prosthesis stability rate of 98.7%. This result was consistent with their observations concerning implants in edentulous subjects. In a retrospective cohort study of van Steenberghe et al (1989), 133 fixtures in 38 patients were examined. Some implants were connected to natural teeth. This study revealed 87% and 92% success for maxillary and mandibular implants, respectively and suggested that osseointegrated implants could be used in the rehabilitation of the partially dentate patient.

In a subsequent evaluation, Naert et al (1992) reported on the observations of 509 implants placed to support 217 fixed dental prostheses. The low failure rates and the acceptable marginal bone changes reported in this "medium-term" follow-up encouraged the use of endosseous implants for the treatment of partial edentulism. A few of the major concerns in this study included the connecting of teeth to implants and the use of porcelain for the prostheses veneers. Regarding the porcelain as an occlusal material, the advantages of esthetics and longevity were considered advantages without risk to the implant or implant/bone interface. They further suggested that there may be no risk in connecting teeth with implants, however they further indicated that freestanding implant prostheses should be made whenever possible. (They reconsidered this comment in an up to 15 year follow up of these patients and demonstrated greater implant failure when implant and teeth are connected (Naert et al. 2002)). Finally, the authors indicated that active efforts to prevent abutment screw loosening and fracture should include the use of passive fitting frameworks, the limitation of bending moments and proper fastening of screws. Today, these early lessons remain central concerns when treating the partially dentate patient using endosseous implants.

Several other investigations concerning implants used for partial edentulism were included in a meta-analysis of Lindh et al (1998). Nineteen studies were included and 2116 implants supporting fixed dental prostheses were involved.

The cumulative survival rate for implants supporting fixed dental prostheses was approximately 97% at inception and 93.5% at five years after implant loading. They concluded that the short-term survival rates were comparable with that of implants in edentulous jaws and represented a strong clinical argument for restoring partially dentate patients with implants.

Zarb and Zarb (2002) reported on the long-term (10-15 year) outcome of implant-supported posterior fixed dental prostheses supported by implants. They recorded the outcome of 25 patients who received 106 Branemark implants and 46 prostheses. The cumulative success rate was 94%. Their 5–15 year data revealed lower survival for men than women (88% vs 97%) that failed to reach statistical significance. The authors recommended the use of implants larger than 10 mm and of 3.75 mm diameter. They suggested the optimal application of three implants for each prosthesis. They favored use of freestanding implant prostheses. In a more comprehensive report of the Toronto experience, Attard and Zarb (2003) reported on 130 patients treated with 432 Branemark dental implants and 174 prostheses. At 15 years, the implant and prosthesis survival rates were 91.6% and 89%, respectively. They further revealed a lower, 76.3% survival rate for 5 mm diameter implants.

These studies are examples of many reports that have provided a level of evidence to treat partially dentate patients with endosseous dental implants. Many are cohort studies and there exist no examples of comparative studies comparing different modalities of treatment or comparing implant prosthesis treatment of partial edentulism to no treatment. However, the aggregate data demonstrate treatment of partially dentate patients with osseointegrated dental implant prostheses is associated with a level of implant survival and prosthesis success that may be accepted by the patient and clinician (Figure 1).

Four Main Concerns Regarding Implant-Supported Fixed Dental Prosthesis in the Treatment of the Partially Dentate Patient

1) Implants in the partially dentate environment with emphasis on periodontal disease as a risk factor for peri-implantitis

The concept that implants are subject to plaque-mediated inflammatory disease of bone and peri-implant mucosa is well established (Mombelli 1993). Contemporary thinking concerning peri-implantitis has been summarized in the Consensus report of the Sixth European Workshop on Periodontology (Lindhe et al 2008). Peri-implant mucositis occurs in a majority of subjects restored with

implants and the incidence of peri-implantitis affecting supporting bone occurs in 12 – 40% of sites. The risk factors include poor oral hygiene, diabetes and smoking, as well as a history of periodontitis. This is supported by a more recent systematic review (Safii et al 2009). Thus, there remains current concern for peri-implantitis in the treatment of partially dentate patients with dental implants. Serino and Strom (2009) indicated that local factors including accessibility for oral hygiene is associated with the presence or absence of peri-implantitis. Implant malposition and poor prosthesis design are factors that can be controlled to aid oral hygiene and reduce risk of peri-implantitis.

The impact of periodontal pathogens is of interest in the partially dentate implant patient and is suggested to be a key difference between the dentate and edentate implant patient. In the year 2000, Hultin et al reported on key biological outcomes for implant prostheses in treatment of partial edentulism. The study involved a 10-year evaluation of 15 patients treated with 2 – 6 implants. They observed no difference between implants and teeth and revealed periodontal pathogens were present at implants with marginal bone loss. The authors concluded that osseointegrated dental implants can be maintained with excellent long-term results in the partially dentate patient.

Wennstrom et al (2004) directly considered implant outcomes for partially dentate periodontitis-susceptible patients. Treatment of 51 patients with moderate-to-advanced chronic periodontists was performed usnig machined and $Ti0_2$-grit blasted implants. After a 5 year prospective evaluation, the observed an overall implant failure rate of 2.7%. The mean total bone-level change over the 5-year interval was 0.41 mm and did not vary between implants with machined or rough surfaces. There remain many questions concerning the risk factors that contribute to peri-implant mucositis and peri-implantitis that are beyond the scope of this discussion. Peri-implantitis is a relevant concern and should be a focus of implant treatment for partially dentate patients.

2) **Implant survival in the posterior maxilla and mandible where bone quantity and quality are relatively diminished**.

Anatomic postion of the inferior alveolar nerve in the posterior mandible and the sinuses in the maxilla limit the height of bone available for dental implant placement. Additionally, the quality of bone in the posterior mandible and maxilla are frequently type III and type IV bone. Since the inception of prognosis based on bone quality and quantity, there has been concern for reduced implant survival in low quality and quantity bone.

In the maxilla, there is support for sinus grafting to increase the bone volume for longer implant placement (Nkenke and Stelzle, 2009). In the mandible, there is little clinical data and less widespread support for lateral nerve transposition procedures (Chrcanovic and Custódio , 2009). When the prospect of vertical bone augmentation was considered in a recent systematic review, there were few studies demonstrating that either guided bone regeneration, distraction ostogenesis or onlay bone grafting reproducibly produced the volume of bone anticipated. The authors concluded that the generalizablity of the approach is limited at this time (Rocchietta et al 2008). This was reiterated in a recent Cochrane systematic review concerning the efficacy of horizontal and vertical bone augmentation (Esposito et al 2009). On an individual basis and with consideration of local factors that affect outcomes, different approaches to increase the height of bone available for implant placement may be used to enhance treatment of partially dentate patients in conjunction with subsequent dental implant placement.

In partially dentate patients needing posterior rehabilitation, the use of short implants with improved surface topography is now of growing interest and may be beneficial in the treatment of partial edentulism. In a study of 1,287 short implants (<8.5mm), a high success rate of 98.8% over a follow-up period of 47.9 (+/-24.5 months) was reported (ref). Similarly, Maló et al (2007) and Grant et al (2009) concluded that 7 - 8.5 mm implants achieved high survival rates in the short to mid-term. The concern for short implant survival in low quality bone of the posterior maxilla has been addressed by many clinical scholars with suggestions for improving outcomes through proper planning, use of additional short implants, the selection of proper loading protocols and the development of controlled occlusal schemes (Bahat, 2000).

The use of short implants implies reduced vertical bone dimension following alveolar resorption. This is frequently associated with long clinical crowns and relatively small implant/crown ratios. Implied is a long bending moment that could affect the prosthesis or implant-abutment connection as well as the implant-bone interface. In a retrospective clinical evaluation, Blanes et al, (2007) demonstrated that implant survival was not affected by implant-crown ratios of 1:1.5 to 1:2.0.

3) Implant prostheses function in circumstances where high magnitude forces may be exerted over large bending moments.

The forces on implants and abutments are associated with the implant number, their distribution and the prosthesis material (Ogawa et al 2010). Evidence that

there are limitations in prosthesis success when implant treatment of the Kennedy Class II scenario is performed was provided by Wennerberg and Jemt (1999). They reported high implant and prostheses survival but recorded 5% screw fractures, 13% screw loosening and highlighted problems when prostheses included canine tooth replacement and when only two implants were involved. These early results indicated implant/abutment connection difficulties that have resulted in evolutionary changes in abutment screws and materials. They have also influenced implant/abutment design. Bragger et al (2001) revealed technical complications of implant- supported fixed dental prostheses were associated with bruxers and revealed that there were more porcelain fractures on prostheses associated with implants than those associated with teeth. More recent reports concerning Morse taper and conical interfaces show low prosthetic component complications (Mangano et al 2009)

While not directly focused on the partially dentate patient, Salvi and Brägger (2009) reviewed the mechanical /technical risk factors on implant-supported prostheses. Bruxism, and the length of the reconstruction, as well as a history of repeated complications were associated with increased complications. They found that the crown-implant ratio, the number of implants supporting the fixed dental prostheses and the type of retention were not associated with increased mechanical / technical complications. Interestingly, none of the mechanical /technical risk factors were associated with implant survival.

A most recent systematic review of survival and complication rates for implant-supported fixed partial dentures with cantilevers showed that this treatment solution is associated with implant fractures (Zurdo et al 2009). The technical complications for cantilever fixed dental prostheses occurred with a frequency of 13–36% compared to 0-12% for non-cantilever prostheses. The most common complications included minor porcelain fractures and bridge screw loosening. It is clear that treatment of partial edentulism using fixed dental prostheses supported by implants involves complications that require surveillance as well as intervention. This concern should be weighed in relationship to the observations concerning partial denture complications, implant supported overdenture maintenance complications and the limitations of tooth- supported fixed dental prosthesis therapy. There remains no direct comparison of mid- to long-term outcomes of treatment of partial edentulism using implants, removable or fixed dental prostheses at the level of the implant, the prosthesis or the patient.

4)**The functional relationship of teeth and dental implants in adjacent anatomic and functional environments**.

The development of dental implant therapeutic solutions for treatment of Kennedy classification I and II partial edentulism may have been influenced by the initial experiences using blade implants that typically included blade implants as terminal abutments for tooth and implant supported fixed dental prostheses. It is generally recommended to avoid such prostheses (Lang et al, 2004). Among the earliest complications revealed for tooth and osseointegrated dental implant supported prostheses was relative tooth intrusion. Apparently, teeth that are supported by a periodontal ligament and dental implants with an osseointegrated tissue interface resolve functional loads in different ways. The natural tooth appears to intrude, resulting in tooth – prosthesis debonding or disruption of interconnectors.

This phenomenon occurs sporadically and it is controversial. For example, Gunne et al (1997) observed no risk of tooth intrusion when implants were connected to natural teeth in situations where these mandibular tooth and implant-supported prostheses opposed maxillary dentures. However, Naert et al (2002) revealed a statistically significant greater risk of implant failure when teeth and implants were connected. This data and other clinical reports suggest that the intrusion of the tooth abutment contributed to implant failure. A recent review of the literature concerning this phenomenon made the following conclusions concerning tooth and implant connections: 1) rigid connectors achieve better outcomes with regard to tooth intrusion, but may invoke greater marginal bone loss and probing depth at the abutment tooth (in direct contrast to this suggestion, Lin et al (2007) recommend that non-rigid connector may more efficiently compensate for the dissimilar mobility between the implant and natural teeth under axial loading forces, but with the risk of increasing unfavorable stresses in the prosthesis) 2) a tooth-and implant-supported prosthesis is associated with higher implant failure rates, lower prosthesis durability and greater complications that demand intervention, and 3) the clinical evidence for or against the connection of endosseous implant and tooth abutments is limited. It has been suggested that the free-standing implant supported fixed dental prostheses is the safest clinical option, although under particular clinical conditions, alternatives involving a combined tooth and implant supported fixed dental prosthesis may be considered (Lindh, 2008).

Contemporary Experiences Support Continued Treatment of Partial Edentulism Using Osseointegrated Endosseous Dental Implants

This brief review of the history of dental implant treatment of partial edentulism with a focus on the Kennedy Class I and II situation has revealed a broad

assumption that the dissatisfaction with removable partial dentures and the problems attributed to them can be effectively addressed by the use of dental implants to support fixed dental prostheses. The acceptance of osseointegrated endosseous dental implants provided alternative methods of restoring the partially dentate patient using free-standing fixed dental prostheses. The concerns regarding peri-implantitis, functional discrepancies between teeth and implants supporting the prostheses, and the potential high risk for endosseous implants placed in low volume and density bone to support high forces exerted over relatively long lever arms have not been dismissed. Fortunately, prosthodontics and the discipline of treatment planning have provided a robust foundation for conservative treatment of the partially dentate patient using endosseous implants. Despite the important, yet unanswered questions regarding implant therapy for the partially dentate patient, predictable implant survival and lasting prostheses with manageable complications may be offered to partially dentate patients seeking comprehensive and satisfying dental rehabilitation.

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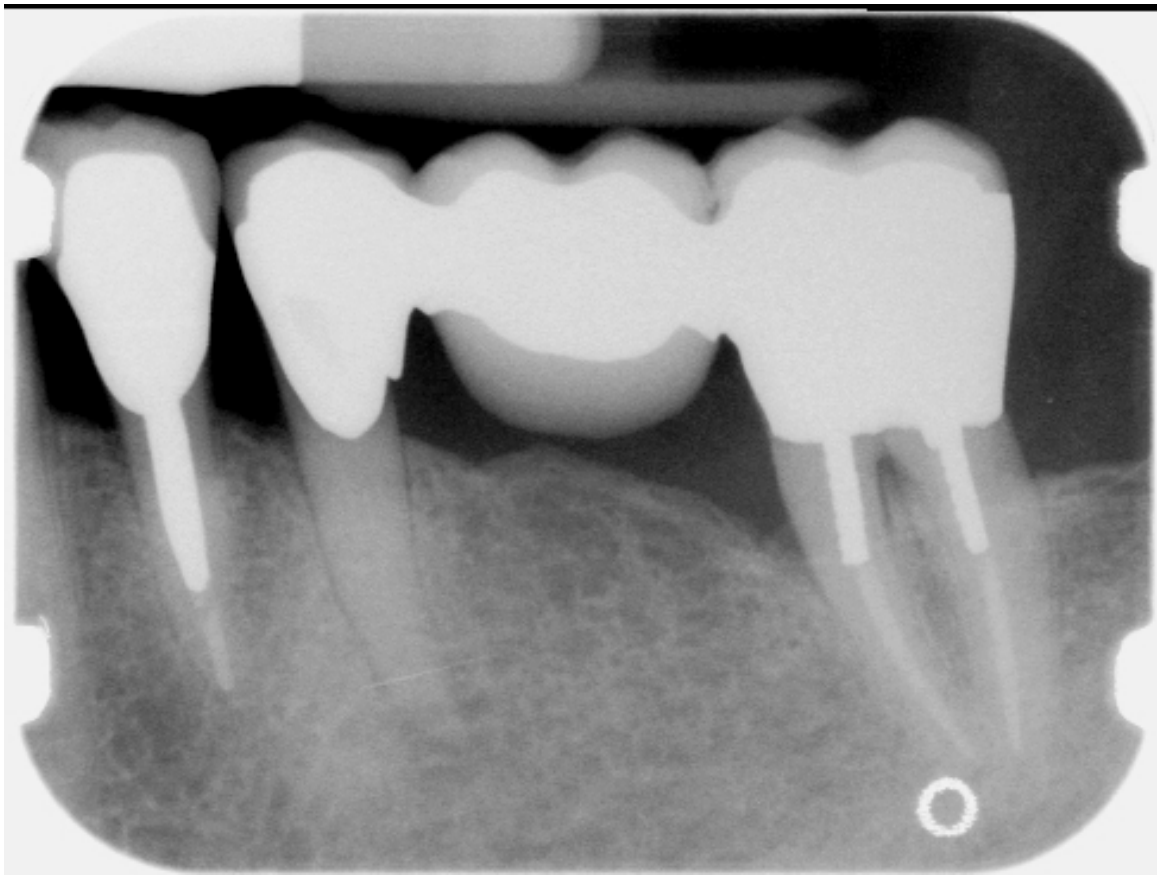

Figure 1a. Condition of FPD three years prior to complication. Note recurrent caries at distal margin of tooth #20 and periodontal involvement of #18. It is noted that the opposing dentition is a three unit implant-supported FPD replacing teeth # 12 – 14. The causes of failure here include both caries and periodontitis. This underlying biologic status must be considered in assessing replacement of teeth using diverse prosthodontic alternatives.

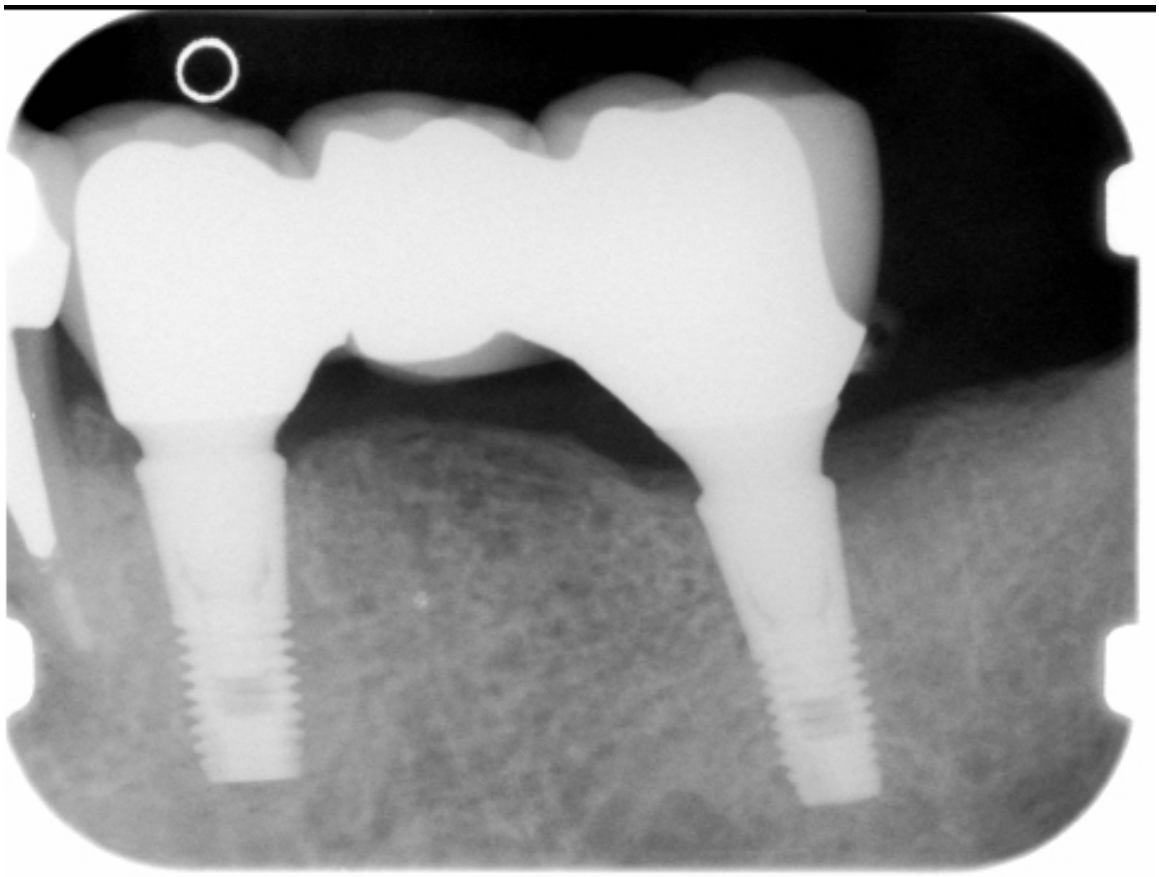

Figure 1b. After failure of the tooth-borne FPD, two implants were placed in the position of tooth #20 and #18 with intention to support the FPD observed in this radiograph. The implants selected provide for the largest implant/abutment interface the selected system provided (AstraTech 4.5 mm implants) and utilized unitary abutment components of robust design (no separate abutment screw). The implant placement was properly organized in existing bone to limit bending moments acting at the implant/abutment interface.

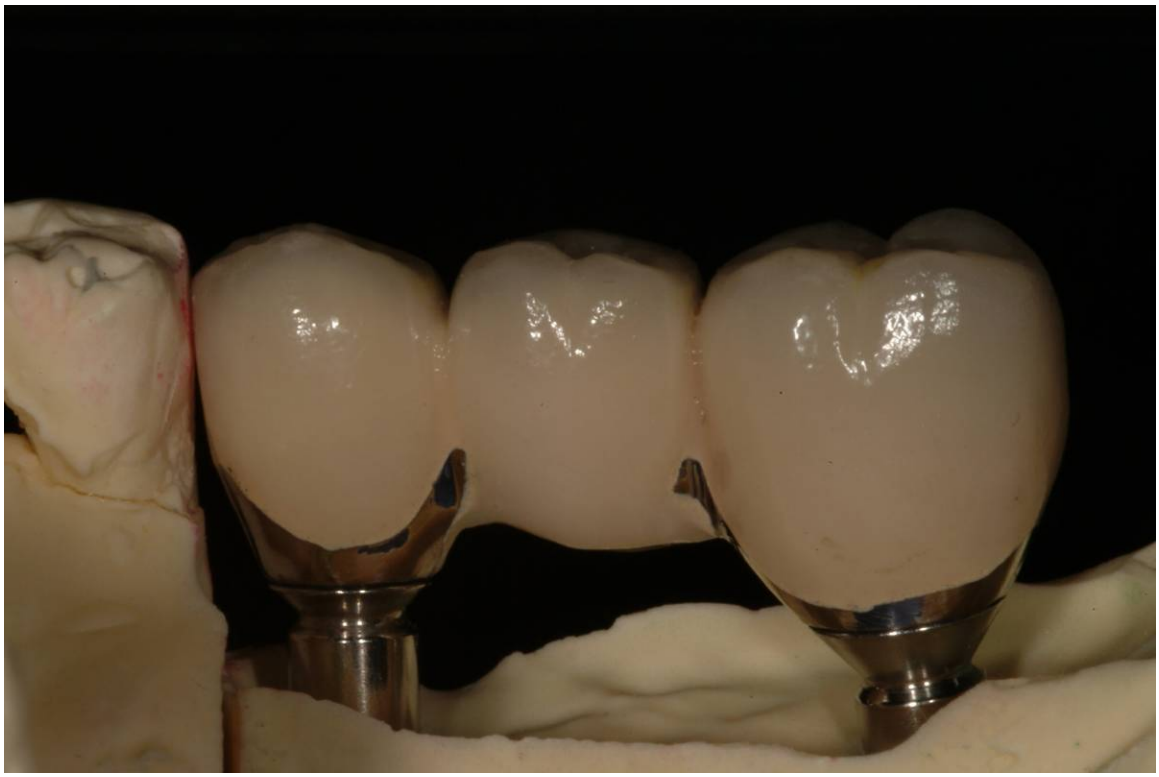

Figure 1c. The implants, the abutments and the FPD framework were designated, placed and constructed according to contemporary understanding of biologic and physical requirements for longevity. The implant placement was properly organized in existing bone to limit bending moments acting at the implant/abutment interface. However, bone levels prior to implant placement require the implant / prosthesis ratio of nearly 1:1. A cement retained construction was selected for convenience, but screw retention for this prosthesis was possible. The framework fully supports the ceramic veneer without imposing on esthetics.

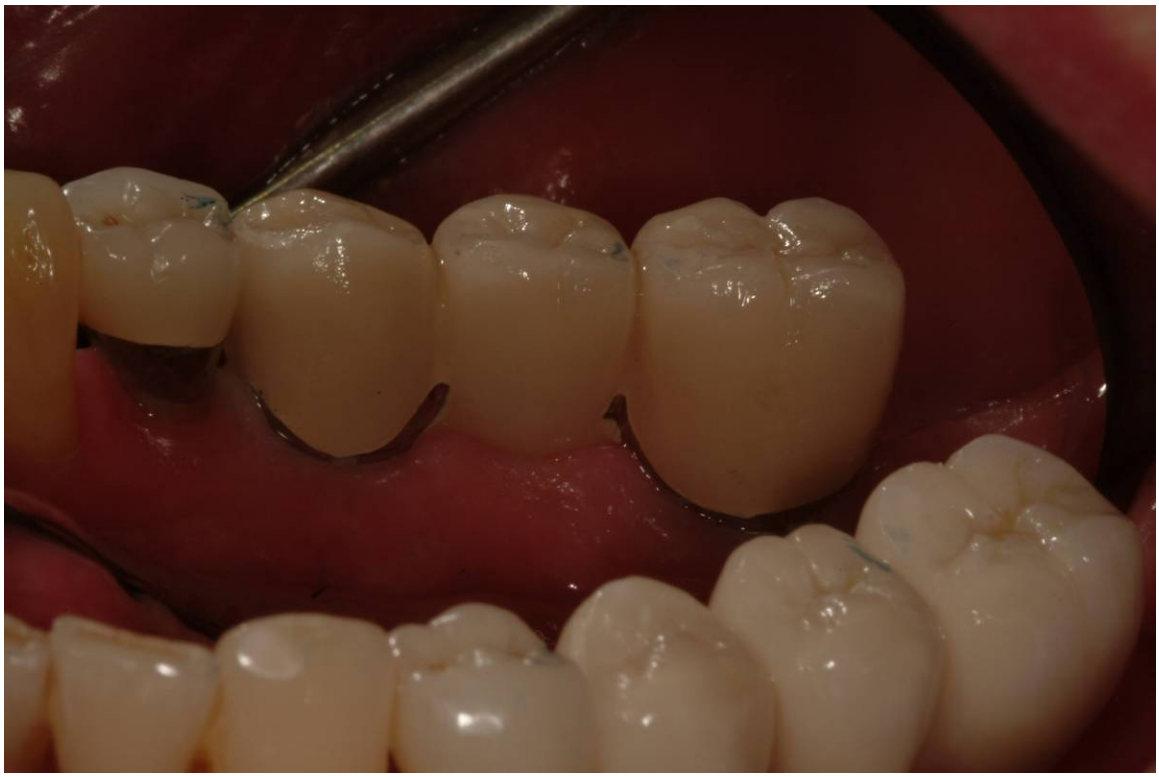

Figure 1d. The definitive prosthesis reveals adequate access to the prosthesis / abutment interface. The relative absence of plaque suggests effort of the patient in maintaining this prosthesis and the remaining dentition. Note that the occlusion has been re-evaluated at this recall appointment to assure that contacts are present in maximium intercuspation position and that disclussion occurred in excursions. Oral hygiene and maintenance are reinforced and potential functional alterations are evaluated at each recall visit. Attention to details in planning, execution and recall of partially dentate implant patients is necessary.

Chapter 3 *An Overview of Maxillofacial Prosthetics*

S. Roy Cohen, DDS, FACP

Maxillofacial prosthodontics, whose goal is to preserve and restore the hard and soft tissues of the mouth and extraoral structures , has undergone significant changes over the last 40 years as new treatment modalities have been introduced and new materials have become available. The principles of prosthodontics have not changed but the improvements in materials and the disciplines of medicine and surgery have aided in advancement in the preservation and restoration of oral and perioral structures. The ability to restore both congenital and acquired defects and prevent further loss has been enhanced by the improvements in the science of materials, the earlier detection of disease, the addition of osseointegration,[1,2] CAD/CAM [3,4] technologies, materials science and many others.

Acquired defects usually are divided by causation into disease, trauma or congenital anomalies. The early detection of cancers [5] and locally invasive tumors and the improvement in cancer treatments from surgical techniques to radiation therapy, with and without chemotherapy, have decreased the size of the oral and perioral defects that remain. Additionally, collateral destruction of healthy tissues that occurred in the attempt to eradicate the disease and advances

in plastic surgery have improved the rehabilitative outcomes. The use of both radiation and chemotherapy as separate modalities or in concert has decreased the defect size and many times eliminated the need for a restoration. The addition of high energy radiation[6] for cancer treatment with the addition of stand-alone chemotherapy or chemotherapy, including the use of cisplatinum [7] for sensitizing cancers to radiation treatment, have reduced post-treatment defect sizes. The treatment of the residual defects is aided by the use of osseointegrated implants in the defect or non-defect side to aid in retention. This advance has added to the success of the prosthetic rehabilitation and improved patient function and satisfaction. [8, 9] The addition of implants to aid in the retention of intraoral prosthesis including removable complete and partial dentures that include obturators has increased their effectiveness and in many cases has eliminated the use of adhesives. [10, 11] The addition of osseointergration and the use of supporting bars have allowed facial prostheses to gain retention without the use of glues. This has improved the retention of the prosthesis and extended the longevity and esthetic appearance of the prosthesis. The prosthesis can be made thinner without the fear of tearing the prosthesis and lack of glue increases the length of time the prosthesis has a natural appearance. Primary stability, retention and treatment outcome are enhanced with the use of attachments that retain the prostheses securely in the oral environment. [12, 13] Advances in surgery including the use of vascular surgical grafts have improved treatment outcomes. The use of three-tissue layer vascular grafts, including epithelium, bone and muscle, to restore mandibular integrity has improved facial contours and function of the final prosthesis.[14] In addition, these grafts could be used for integrating with dental implants to support a fixed or removable partial denture or complete denture. [15, 16] Post-cancer treatments that leave the patient with a soft palate defect have traditionally been treated with removable appliances and obturators. More recently many of these defects have been treated surgically, however the outcome of the traditional prosthodontic treatments using a removable appliance and obturator has equal patient satisfaction and objective speech quality. [17]

The advancement in passive automobile restraints has diminished the numbers of facial acquired defects, but the trauma to the head and face occurring during combat conflicts [18] has increased the need for the prosthodontic aid in the post-surgical restoration of military wounded. Osseointegration and CAD/CAM technologies, as well as the advancements in bone grafting using both autogenous bone and cadaver bone, have aided in the rehabilitation of these defects. Adult stem cells have recently been used to infuse a hard matrix used to replace native bone [19] and soon will support the growth of new bone in the

proper dimensions in the proper place. The use of these types of grafts allows the restoration of bony integrity and the use of osseointegreted implants to support a prosthetic restoration.

The treatment of cleft palate and craniofacial defects, in addition to the treatment of patients with developmental defects such as ectodermal dysplasia, has improved with the advancements in materials and the addition of osseointegration. Forty years ago the maxillofacial prosthodontists had a key roll in the treatment of cleft palate and craniofacial anomalies. While the role is still important to the cleft palate team, the role has changed. The lip was usually closed and the craniofacial defects managed surgically, however the hard and soft palate defects were left ungrafted after the rehabilitation surgery. [20] In addition, the alveolar cleft was usually left unrepaired and the maxillary arch was without cross arch integrity or stability. Maxillary prostheses that obturated the hard and soft palate were used to complete the treatment. A speech bulb was added to the prosthesis to allow for an increase in oral pressure to produce proper speech. In the late 1960's, advancements led to surgical corrections of the hard and soft palate. [21] In late 1960's and early 1970's, the hard and soft palates were closed and the alveolar cleft was grafted with autogenous bone grafts. [22] After the union of the segments, fixed restorations could be delivered with confidence, [23] knowing that the segments would not need to be splinted through the fixed prosthesis. However, splinting the maxillary segments with a fixed bridge could lead to early failure of the teeth. With the advent of Resin bonded fixed prosthesis described by Livaditus and Thompson, in 1982, [24] a procedure was developed to replace the missing adult teeth with a combination of a fixed bonded bridge and a detachable pontic, without the need for full coverage restorations on the abutment teeth.[25] This improvement allowed the preservation of tooth structure while restoring both the residual hard and soft tissue defects. As osseointegration became more accepted by the profession and the outcomes more predictable, implants were used to replace the missing teeth in the cleft defect.[26] The maxillofacial prosthodontists role in the treatment of cleft palate and craniofacial anomalies has become more focused on guiding the rest of the team towards the goal of a complete rehabilitated dentition and normal scaffolding for the facial plastic reconstruction. The use of fibrin glue and chondrocytes to mold cartilage has been reported [27]. This cartilage can be used for scaffolding to improve the plastic surgical outcomes in rehabilitation of the cleft-craniofacial patient. The prosthodontist is also involved in facial molding both before the closure of the lip and after to increase the columella length and better adaptation of the segments for the hard palate closure. [28]

Prosthodontic care of the radiation patient has had two paradigm shifts in the last 40 years. The first was the use of fluoride to reduce decay after radiation treatment developed at The University of Texas Dental Science Institute and MD Anderson Hospital in Houston, Texas in the late 1970's [29] and the second was the use of hyperbaric oxygen to prevent and treat osteoradionecrosis. [30] At the time, the loss of a tooth after radiation could be a life threatening condition. [31] After external beam radiation to treat oral cancers became widespread, the caries rate from the xerostomia caused by the radiation would increase to unmanageable levels. With the advent of daily topical fluoride applications, the caries incidence from xerostomia induced by radiation decreased the loss of teeth, and therefore the danger to the patient also diminished. Fluoride trays and aggressive caries control was imperative. Teeth subjected to a dry oral environment have historically been at risk, however, new products have become available to suppress the demineralization and enhance remineralization. One of these is casein phosphopeptide-amorphous calcium phosphate (CPP-ACP).[32] Splinting of teeth was used to maintain the teeth in the arch to avoid extraction and necrosis of the jaws. With the advent of hyperbaric oxygen the need to hold on to teeth at all costs was no longer imperative. Included in the normal protocol for extractions with the addition of antibiotics, [33] the use of hyperbaric dives reduce the danger of tooth loss leading to necrosis for the post-radiation patient. The addition of hyperbaric oxygen has also allowed the introduction of implant supported prostheses to restore the edentulous and partially edentulous patient [34, 35]. This has been particularly helpful to the edentulous patients with xerostomia post-radiation therapy. The patient's ability to successfully wear a denture is diminished by the oral condition including dry mouth and friable tissues; however, the use of osseointegrated implants has facilitated treatment with both fixed and removable prostheses.

Maxillofacial prosthodontists have been supporting radiation oncologists during the last 40 years making radiation carriers for radiation seeds and stents to mask areas to reduce total radiation.[35] In addition, templates are fabricated for positioning and for optimizing and concentrating the radiation to irregular body parts like the ear or nose**.** Prosthodontists have also made radiation carriers to position radiation seeds in juxtaposition to a tumor for direct concentration radiation levels. These carriers can be made with or without shields at the prescription of the radiation oncologist. [36, 37, 38]

The future of maxillofacial prosthodontics will change as material, medical/ surgical care and the needs of our patients change. The basic principles of preserving what remains and restoring what is missing will always guide the profession. With the addition of new modalities of bone formation, enhanced repairs and growth of new tissue, maxillofacial prosthodontists in the future may use more natural replacements for missing parts than we have used in the past. Our future is bright and the next forty years will see as much or more change as we have seen in the past.

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Chapter 4 *Advancements in Maxillofacial Prosthetics*

John Wolfaardt, BDS, MDent, PhD; Thomas J. Vergo Jr., DDS; Lawrence E. Brecht, DDS, Terry M. Kelly, DMD, Jeffrey E. Rubenstein DMD, MS and Robert Gillis, DMD

Maxillofacial Prosthetics (MFP) is the subspecialty of Prosthodontics that restores form and function of defects of the head and neck region secondary to congenital and developmental or acquired oncological and traumatic anomalies. MFP, more than any other aspect of Prosthodontics, has a very close relationship with the medical profession, so it is not surprising that one of the most significant advancement experienced in MFP is linked to advancements in surgical reconstructive techniques. Likewise, advancements in technology have had a profound impacted on MFP. Expanded use of implants in the MFP patient has had an equally profound impact on the MPF restoration of form and function. The assignment of CPT codes for the most common procedures in maxillofacial prosthetics standardized the procedural terminology. And, lastly, prospective clinical trials to develop new treatment techniques and assess outcomes have improved treatment strategies.

Advanced Digital Technologies

Contributor: Dr John Wolfaardt, BDS, MDent, PhD.

Advanced digital technologies (ADT), as agents of change, offers maxillofacial prosthetics/prosthodontics, the opportunity to become the most significant

component of dentistry in delivery of care in support of restoring form and function. Moreover, ADT draws maxillofacial prosthetics into not only interdisciplinary activity in surgery of the head and neck, but also into a far wider interaction with diverse surgical and medical disciplines. In this respect, ADT offers maxillofacial prosthetics and prosthodontics remarkable expansion of opportunity in care delivery and future discovery.

The future value of Knowledge Work has had a profound effect upon society and corporate thinking over the past 50 years. A primary tool of the knowledge worker, an individual who is valued for his/her ability to interpret information within a specific subject area, is digital technologies and the connectivity they provide. Peter Drucker[1] provided considerable insight into the importance of knowledge work for the corporate world during the 20th Century, and this legacy continues. It is expert knowledge of the use of these technologies, as tools, that defines a knowledge worker's ability to participate in and contribute to an economy. It is this fact that the surgical and surgically related disciplines have to grasp with some urgency. For the most part, much of maxillofacial prosthetics, as it is practiced today, uses technology and manual processes that have remained largely unchanged for over six decades. This remains so in a period that has seen incredible technological advances in related areas such as digital imaging, minimally invasive surgery, navigation, robotics, and the like. Curiously, maxillofacial prosthetics is particularly well positioned to become the technological integrator with ADTs as it is maxillofacial prosthetics that has the interconnecting clinical role with a broad base of knowledge of the various surgical/medical disciplines.

The range of ADT technology options involve a panorama of new applications such as imaging (CT Scanning, CBCT Scanning, MR Imaging, Sonography), simulation applications (surgical simulation software, implant installation simulation software), prototyping applications (rapid prototyping, rapid manufacturing), prototyping hardware (additive, subtractive, wide variety of materials), scanners (probe, photogrammetry, laser), color scanning and formulation, 3D haptic design tools, endoscopy, navigation and robotics. These and other tools make for an astonishing array of ADTs available to the maxillofacial prosthodontist. It is no longer unusual for the maxillofacial prosthodontist to consider digital design of a tumor resection and to plan a microvascular reconstruction for a jaw with rapid prototyping tools, or to construct an obturator from a CT scan with printing of the obturator pattern, design a cranioplasty with a haptic interface tool or designing and constructing elements of an auricular implant or autogenous reconstruction with imaging and

prototyping tools. While this work is becoming increasingly commonplace, the question remains as to why many maxillofacial prosthodontists continue to function in largely manually driven environments. There is risk in this situation continuing and the threat lies in Peter Drucker's caution that those who do not transition to Knowledge Work will find obsolescence.[1] The challenges to adoption of ADTs by maxillofacial prosthodontics are real and require attention. Many of the technologies are borrowed from Industry, are not adapted to clinical use and are true to Christensen's[2] concepts of being disruptive technologies. The utilization of the technologies has run ahead of development of health economic understanding of ADTs. Willingness to pay by fund holders remains a challenge as does cost of technology acquisition and maintenance. Perhaps the major hurdle remains the lack of formal teaching to residents of ADT utilization, the management of disruptive technologies and the business models for technology adoption. A further important need is development of technologists to operate many of the ADT systems. This is analogous to a radiologist having sophisticated digital imaging technology, but no radiation technologist to operate the equipment. These are important matters to resolve as it may be speculated that ADTs will play a critical role in attracting younger generations to the field of prosthodontics and maxillofacial prosthetics. This is attributed to the understanding that more recent generations do not want to be trapped between the manual and digital technology eras.

For all the challenges with ADT adoption, it is beyond remarkable how very rapid the adoption and how transformative advanced digital technology has been to the field of maxillofacial prosthetics. We now find professional development activities and international conferences dedicated to ADTs in head and neck reconstruction, the first text on medical modeling by Bibb[3], a Master of Science program established in surgical design and simulation,[4] and curricula being revised to incorporate digital technology. These changes herald the fundamental shifts that will move maxillofacial prosthetics through transformative change to a future of functioning in a digital world of technologies that are developing and converging at an incredible pace. The importance of the Prosthodontists role in this technology convergence carries strategic value to healthcare. The strategic value of participation in technology convergence was amplified by Rocco and Bainbridge[6].
ADT has brought profound change to maxillofacial prosthetics. The implementation of this change and where it truly delivers value is under debate. Remarkable too, is that technology rich developing countries faced with large patient numbers such as China and India are showing increasing interest in ADTs. This is attributed to the potential ADT holds for catalytic innovation

potential to change care delivery on an exponential scale with driving down cost and making care available to large numbers of patients. Maxillofacial prosthetics is thought to be inextricably linked to advanced digital technologies as the foundation knowledge work domain of the discipline for the future.

Mandibular Defects

Contributor: Thomas J. Vergo, Jr., DDS

Curtis and Cantor[1] originally coined the term "the forgotten patient in maxillofacial prosthetics" in their classic article reviewing the clinical treatment options when treating a patient with a discontinuous mandible. Over the years many authors [2-6] have described intraoral prosthesis designed to either "prosthetically" reposition the residual mandibular segment into a more favorable occlusal relation or to accept the deviated mandibular position and provide an eccentric occlusion. Nowhere is the skill of diagnosis and treatment planning more complex and the range of treatment choices greater then with the patient who has undergone surgical resection (or traumatic loss) of part of the mandible when considering prosthodontic rehabilitation.[7]

Significant advances have been made in the area of microvascular and reconstructive surgery over the past 30 years. However, mandibular defects remain a difficult challenge for reconstructive surgeons. The challenge is to restore airway support, oral competence, verbalization, mastication, deglutination, and acceptable aesthetics, allowing the patient to return to society.[8]

Treatment strategies range from a post-surgical "wait and see" attitude on the part of the treating surgeon for a given length of time to rule out a recurrent tumor to immediate or post-radiation surgical reconstruction to restore the continuity of the mandible using pelvic bone grafts, grafts from the lateral part of the scapula or part of the fibula include the blood vessels to ensure the blood supply of the graft; all with or without the aid of implants to stabilize the intra-oral prosthesis.

A recent longitudinal (within-subject), prospective study by Garrett, et al,[9] looked at patients who underwent partial mandibulectomy surgery resulting in lateral or anterior composite defect, which were reconstructed with a free flap. Implant placement in the graft bone was delayed and a conventional removable prosthesis (CP) was fabricated and evaluated by the patient. After approximately 4 months of functioning with the conventional prosthesis,

implants were then placed in the graft bone, implant supported prosthesis (IP) fabricated and evaluated.

Most of the study conclusions were predictable: 1) the patient's masticatory ability after partial mandibulectomy and reconstructive surgery "approached" pre-surgical levels when restored with the CP and IP; 2) however, the masticatory performance scores with both prostheses were similar to those of a conventional denture wearer 3) While EMG and jaw movements varied greatly, increased stability with the IP may permit greater muscle effort on the defect side, 4) masticatory function with the IP was significantly greater than with the CP on the defect side, 5) chewing ability and denture satisfaction and security showed the greatest change with IP supported denture treatment and 6) 29% accepting CP as sufficient!

Of the 36 subjects enrolled with malignant tumors, 16 (44%) experienced recurrence, metastasis or death within 13 months following ablative/reconstructive surgery. Therefore, one of the unexpected conclusions was that caution must be taken in deciding the timing of extensive implant prosthetic procedures suggesting that CP should be provided for the 1st year post-surgery and assessed for cancer treatment outcomes, functional levels and patient expectations before considering implants.

Nasoalveolar Molding ("NAM")

Contributor: Lawrence E Brecht, D.D.S.

Nasoalveolar molding or "NAM" (a form of presurgical infant orthopedics) was developed to help improve the functional and esthetic outcome in infants born with cleft lip, alveolus and palate. It was advanced by the team at the Institute of Reconstructive Plastic Surgery at New York University Medical Center in the mid-1980's and has significantly improved the appearance of children born with either a unilateral or a bilateral cleft. While presurgical infant orthopedics was original developed in the early 1950's by a prosthodontist, McNeil, the technique fell out of use. Studies have shown that nasoalveolar molding reduces the severity of the cleft deformity *non-surgically* and therefore allows the surgeon to perform a less extensive surgical procedure in repairing the cleft. Usually, only one surgical procedure is required to repair the lip, nose and alveolus following NAM therapy. If the palate is also cleft, a separate surgery is still required to close the palatal defect. The result is less scarring and significantly improved facial esthetics when objectively evaluated.

NAM treatment has also shown to reduce the overall number of surgeries a patient will usually have to undergo during their lifetime to achieve an improved esthetic outcome. In the unilateral condition, there is a reduction in the need for subsequent alveolar bone grafting at age 8 or 9 by over 70% and in the bilateral condition, there is an approximately 40% reduction in the need for bone grafting. Similarly, the early improvement in nasal esthetics nearly eliminates the need for early nasal revision surgery at the time that a child enters school. It also appears that noses that have been treated by NAM follow a growth pattern that tracks parallel to normal, non-cleft noses.

Nasoalveolar molding provides maxillofacial prosthodontists with the ability to vastly improve the course of facial development for infants with cleft lip and palate while reducing the number and extent of surgical procedures they must undergo to treat their condition. [1-4]

RVU

Contributor: Terry M. Kelly, DMD

The assignment of CPT codes for the most common procedures in maxillofacial prosthetics in 1993 marked the inception of a concerted effort by the American Academy of Maxillofacial Prosthetics to standardize the procedural terminology that would ultimately serve as the template for coding and reimbursement for these procedures as part of the health care system.

The original version of the CPT system was introduced in 1966 as a method to standardize medical procedure terminology to facilitate communication between physicians, hospitals, and laboratories. At the time, the prevailing method of compensation for health care services in the Medicare system relied on charged based data in a relative value scale that was fairly similar to the "customary, prevailing, and reasonable" system used in the insurance industry. In 1985, the HCFA (Health Care Financing Administration) initiated reform of the reimbursement process in the Medicare system which led to the development of the RBRVS (Resource Based Relative Value System) by a Harvard economist. This was designed to correct the arbitrariness, inaccuracies, and discrepancies in the reimbursement process, by recognizing the shared components of all procedures included in the decision making process. By 1992, the RBRVS was implemented as the basis for reimbursement within the Medicare system. The AAMP was well aware of the implications that this held for the future of the sub-specialty. As such, the AAMP created two workshops which convened in Chicago, IL in November 1992, and February 1993, designed to evaluate the newly assigned CPT coded procedures 21076-21088, generating data for

development of RVU's to be submitted to the AMA for consideration and assignment of values for each code. The final rule was published in the Federal Register in 1996, assigning unique, individual values to each CPT coded procedure which would now serve as the basis for reimbursement within the Medicare system. The AAMP continues to work to address concerns regarding particular components of the RBRVS such as RVUpe (practice expense), to ensure the data is accurate and reflects the modern day practice of maxillofacial prosthetics. [1-3]

Craniofacial Prostheses/Implants

Contributor: Jeffrey E. Rubenstein DMD, MS

Prosthodontic management of patients experiencing compromise/loss of facial anatomy resulting from surgical resection of tumors, trauma, or congenital anomalies represents a challenging area of rehabilitation from a functional, esthetic and psychological perspective. Attempts to replace missing facial structures date back as far as two thousand years ago based on anecdotal reports, historical records, and archeological findings. More recently adhesive and or mechanically retained extra-oral prostheses were considered the standard of care. However, surveys of patients so treated noted that retention or lack thereof was the rate limiting step for their acceptance of such treatment.[1,2]

The remedy for compromised retention of facial prostheses was introduced in the late 1970s by P.I. Brånemark et al, a natural extension from that of osseointegrated implant rehabilitation for the edentuolous patient.[3] The initial introduction of the use of the craniofacial implants in the United States was first reported by Dr. Steven Parel in the inaugural edition of the International Journal of Oral and Maxillofacial Implants.[4] The U.S Food and Drug administration mandated a multi-center prospective clinical trial before sanctioning clinical use of the craniofacial implant. This study was conducted amongst 19 participating centers and the results of this clinical trial led to their FDA approved clinical application. The application of craniofacial implants to retain facial prostheses then was widely applied and retrospective reviews of this effort were reported.[6,7] Among the findings from these retrospective reviews was the fact that varying levels of craniofacial implant success was noted for treatment sites and as well patients having been irradiated demonstrated a higher failure rate than those who had not been so treated.

As well, the types of retention/prosthetic designs were investigated. [8] While the majority of craniofacial implant retained extra-oral prostheses are retained by clips and/or magnets, the use of an array of attachments has been applied to this

treatment approach. Little scientific evidence has evolved thus far as to what the optimal approach is for retaining extra-oral prostheses despite now having a mechanism to do so. In sum and substance, the introduction and use of craniofacial implants to provide a mechanism for retaining extra-oral prostheses represents a major advance in the management of patients needing this type of rehabilitative intervention. The future developments in this arena offer exciting opportunities to further develop and improve current methodologies for implant retained craniofacial implant prosthodontics.

Future Considerations

Contributor: Robert Gillis, DMD

It should be emphasized that many aspects of maxillofacial prosthetics have had little or no advancement. Facial materials have been refined when compared to the materials that we began using 35 years ago, however there has not been development of a "new" material. Although we emphasize early detection in our fight against head and neck cancer, cure rates have not improved in 40 years. Perhaps we need to stress physicians doing oral screenings in the at-risk populations since they see these patients seven to ten times more frequently than dentists in patients who are found to have head and neck cancer.: We need to initiate studies to provide data for a more comprehensive regimen to include antimicrobial rinses, varnishes, re-mineralization products and appropriate restorative materials to improve caries prevention in xerostomia patients. And, lastly, with the advancements we have experienced in surgical reconstruction of the head and neck defect patient, we need to develop protocols and recommendations for the most effective surgical and prosthetic reconstructive measures based on outcomes.

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Dr. Kelly attended the University of Illinois, and graduated from Southern Illinois University School of Dental Medicine in 1984, receiving the Dentsply Award for outstanding achievement in fixed prosthodontics. Following a residency program in Prosthodontics at Louisiana State University, Dr. Kelly completed a fellowship in Maxillofacial Prosthetics at M.D. Anderson Hospital and Cancer Institute in 1987. That same year, he accepted a faculty position in the Department of Surgery at the University of South Florida College of Medicine, and became the Director of Maxillofacial Prosthetics at the H. Lee Moffitt Cancer Center in Tampa, FL. Dr. Kelly received the 1989 Annual Research Award of the American Academy of Maxillofacial Prosthetics, and became certified by the American Board of Prosthodontics in 1991. Dr. Kelly is a Past President of the American Academy of Maxillofacial Prosthetics, Florida Prosthodontics Association, and a Regional Director of the American College of Prosthodontists.

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Dr. Robert Gillis is a 1966 graduate of the College of the Holy Cross. He earned his DMD degree in 1970 from the University of Medicine and Dentistry of New Jersey. He completed a rotating internship in the U.S. Public Health Service and served as a staff officer for two additional years at Norfolk, Virginia. He completed a three year combined residency in Prosthodontics and Maxillofacial prosthetics at the Mayo Graduate School of Medicine and received an MSD from the University of Minnesota. From 1976-1978 he was on the faculty at UC San Francisco funded by a national Cancer Institute grant. From 1978-1983 Dr. Gillis served as Director of Dentistry achieving the rank of clinical associate professor at UC Davis, School of Medicine department of Otorhinolaryngology. He has had a private practice in Sacramento from 1978 to the present. Dr. Gillis is a member of a number of other prosthodontic organizations including the American College of Prosthodontics, the Academy of Prosthodontics, the American Academy of Maxillofacial Prosthetics (past president) and the Pacific Coast Society for Prosthodontics (past president). He is a diplomat of the American Board of Prosthodontics. He is a member of the Sacramento District Dental Society, California Dental Association and American Dental Association. He is a Fellow of the American College of Dentists.

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Chapter 5 *Maxillofacial Traumatic Injuries*

Jonathan P. Wiens, DDS, MSD, FACP

Trauma is the fifth leading cause of accidental death. There are twice as many unintentional injuries as intentional injuries. Injury incidence for ages 5 to 44 will exceed all other disease incidences for the same age group. Trauma from motor vehicle accidents is the leading cause of death (41,000/year) and results in 1.3 million facial injuries annually. Fatal firearms injuries have been estimated at 33,000 per year, while non-fatal head wounds are estimated at 100,000 year. Wartime injuries from projectiles and explosive blasts will create greater injuries due to the magnitude of the event.

The prosthodontist will participate in managing the care of maxillofacial traumatic injuries caused by physical contact, heat, electrical and chemical agents. Traumatic injuries of the maxillofacial region will vary from discrete areas to extensive avulsion of both hard and soft tissues. Localized defects typically result in avulsed teeth and alveolar bone that may be managed by surgical and prosthodontic reconstruction.

Traumatic injuries often create partially edentulous zones that are both tooth bound and non-linear. The accompanying alveolar boney defects are more

extensive compared to tooth loss from dental diseases. Injuries to teeth may be classified as 1) fractures, 2) irreversible pulpitis/periodontal attachment loss and 3) subluxations and/or avulsions that result in tooth loss. These anatomical limitations increase the demand upon the remaining dental-alveolar structures. Traumatic impacts may also create oblique forces that result in distant injuries to the muscles, temporomandibular joint and condyles. These injuries will create difficulties in normal jaw function and reconstructive efforts. More extensive oral-facial injuries will include loss of maxillomandibular continuity to possible central nervous system deficits that impact sensory deprivation, velopharyngeal and tongue function.

Treatment goals for the trauma patient include psychological counseling, oral intake and circumoral competence, mobile-sensate tongue, closure of palate and maxillomandibular realignment, and the restoration of physical appearance. Treatment planning will require careful assessment for bone grafting, implant placement and crown restorations with fixed and removable dental prostheses.

Jonathan P. Wiens received his DDS from the University of Detroit and completed advanced prosthodontic training in fixed and removable prosthodontics and maxillofacial prosthetics at the Mayo Graduate School of Medicine. Dr. Wiens is a Diplomate of the American Board of Prosthodontics and currently serves as a Board Examiner. He is the President Elect of the American College of Prosthodontists.

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Chapter 6 *All-Ceramic Restorations: Vision, Discovery and Predictability*

Robert Kelly, DDS, MS

Fortuitously, the College's first 40 years coincides with both an astounding improvement in our ability to recreate the optical and functional characteristics of natural teeth as well as with my own involvement in dentistry and materials science (± 5-6 years). So this contribution provides me the opportunity to present a "first person" viewpoint on an unprecedented evolutionary period of our ceramic resources and our esthetic and functional capabilities. Such perspective necessarily blends both the historic and the scientific, thereby also providing potential insights into coming attractions. My intention is to focus mainly on earlier work and discoveries since knowledge of these pioneering contributions is becoming hazy and lost.

One of my favorite lecture devices when softening-up "Ceramics 101" audiences by weaving in the history of ceramics use in dentistry, is to ask a loaded question: "During anytime from 1774 through today, our incorporation of ceramics into dental practice resulted from (1) borrowing "craft art" or (2) incorporating "high technology?" This then necessitates agreeing upon a definition of both. "Craft art" is usually understood as involving materials or methods derived from jewelers and artisans. "High tech" is a bit more complicated, including the likes of: (1) capitalizing on recent scientific literature

outside of dentistry (engineering, chemistry, materials science); (2) co-opting a recent invention from an unrelated industry/profession; or, (3) involving an invention unknown either within or outside of dentistry. Most hands go up for "craft art" as would mine before I engaged in an historical review of ceramics in dentistry for a 2001 meeting of the Academy of Prosthodontics. The answer is clearly "high tech" at every important developmental stage, including the last 40 years. Another "universal characteristic" is that all major developments in ceramics were responsive solutions to specific problems. Problems of hygiene, fit, esthetics, fracture, and the extension of clinical indications have engaged visionary dentists for centuries, most often in collaboration with a science/engineering partner (or alchemist!).

Dispersion Strengthening of Glasses – Dr. John McLean and General Electric

In 1965, dentistry was presented with a pivotal paper due to the interest of John McLean to introduce polycrystalline ceramics (particularly alumina) as a framework material for all-ceramic prostheses.[1] Dr. McLean worked with T.H. Hughes, a materials scientist with the Warren Spring Laboratory, Stevenage, England. It had been known for decades that metal alloys could be strengthened by the uniform addition (dispersion) of small, hard particles (e.g. carbides in high strength steel). It was not until the late 1950's and early 1960's that ceramic engineers began to realize that glasses could be dispersion strengthened as well. Adding small particles such as aluminum oxide (alumina) to a glass could either weaken or strengthen the system depending on particle size, volume fraction, differences in thermal expansion behavior (glass-alumina) and chemical reactivity. Early works on the intricacies of dispersion strengthening of glass were being explored in 1959 through 1962.[2-4] Work aimed at understanding and modeling the newly developed strengthening effect of dispersed particles in glass began about 1966 and continued through about 1983.[5-9]

By 1962, knowledge that glasses could be strengthened by crystalline particles was appearing at the textbook level and was known to Dr. McLean and T.H. Hughes by experimentation as well.[10] In about 1967, Vita Zahnfabrik (Bad Säckingen, Germany) introduced the alumina-filled feldspathic glass formulation of Dr. McLean and T.H. Hughes as the first commercially-successful substructure ceramic (Vitadur-N) along with a specially matched veneering porcelain (Vitadur Alpha). Both of these variously became called "aluminous porcelains" by the dental community.

Also in 1965, General Electric switched to alumina from sand as the filler in their porcelain-based insulators for high-tension power lines for improved strength. This places dental materials on the cutting edge in either adapting emerging science from ceramic engineering literature or in following an unrelated industry in technology development. Yes, this counts as "high technology" under the above definition by either (1) capitalizing on recent scientific literature outside of dentistry (engineering, chemistry, material science) or (2) co-opting a recent invention from an unrelated industry/profession. In addition Dr. McLean, clearly a visionary dentist, collaborated with an engineering partner to address problems of fracture, esthetics and fit.

Non-Shrinking Ceramics I – Drs. Sozio and Riley Encounter Adolph Coors Co.

The next exciting development in dental ceramics involved not just a novel material but, more importantly, the first introduction of any advanced ceramics processing equipment into the dental laboratory since the electric porcelain furnace in 1905. It is also another clear example of visionary dentists collaborating with a materials science colleague in search of solutions for dentistry.

Ralph Sozio and Ted Riley took the problem of ceramic shrinkage to Brian Starling of Coors Biomedical. Most people only associate Coors with their delightful beverage, not realizing the firm's long-standing role in ceramic engineering. The Adolph Coors Company has among its subsidiaries CoorsTek (formerly Coors Porcelain and then Coors Ceramics), Coors Biomedical, and was involved in endowing the Colorado Center for Advanced Ceramics at the Colorado School of Mines in 1988 (gift of the widow of Herman Coors). In close collaboration with prosthodontists Sozio and Riley, Coors Biomedical developed a novel transfer molded ceramic (pressed) and an abrasion-resistant epoxy die.[11,12] The ceramic (Cerestore) was considered to be "net shape" meaning that there was no change in shape from unfired greenware to the fired part (i.e. non-shrinking). The refractory components of the material included Al2O3 (60 mass%), MgO (9 mass%), and a barium aluminosilicate glass (13 mass%). In its green state this material also contained enough silicone resin (12 mass%) and kaolin clay (4 mass%) to impart sufficient plasticity for transfer molding at 160 °C onto an epoxy replica of the prepared tooth.13 Its net-shape capability following firing up to 1300 °C was ascribed to the formation of magnesium aluminate spinel (having a lower density than the parent oxides), but more likely involved oxidation of the silicone resin with an expansion of a closed pore phase.[13] In essence this ceramic expanded within its closed mold like a little loaf of bread.

Unfortunately the high volume fraction of closed pores limited its strength/toughness, and the licensee, Johnson & Johnson, removed it from the market with 3 to 4 years of its introduction.

Both transfer molding (pressing) and microprocessor-controlled firing were introduced into dental laboratories establishing a milestone in the evolution of that industry from craft art to its complexion today mixing artistry and automated technologies. Audiences I speak to today have no memory of Cerestore. Hopefully this article begins to revive knowledge regarding this pivotal example of high technology leadership provided by Drs. Sozio and Riley in their involvement with Brian Starling and Coors Biomedical on behalf of prosthodontics.

Non-Shrinking Ceramics II – Corning Inc. Discovers Dentistry

In 1957 Corning Incorporated developed a novel class of ceramic materials in which toughening filler particles were precipitated and grown inside of a clear starting glass; these materials were termed "glass ceramics". In 1972 David Grossman of Corning reported on the development of a specific glass ceramic that could be machined with ordinary tools.[14] This ceramic, trade-named Macor, contained interlocking flakes of tetrasilicic fluromica crystals (55%) in a borosilicate glass (45%) and had the appearance of porcelain or ivory. Collaboration on dental applications of Macor between Corning and Peter Adair (first with Biocor, Inc. and later Dentsply International) were first reported in 1984.[15] Armamentarium for crown fabrication included a specialized centrifugal glass casting machine and a dedicated ceramming oven to crystallize the clear glass castings. This dental ceramic was trade-named Dicor, a conjugation of "Dentsply International and Corning". Color was added by surface stains and opacity was developed by a reaction between the glass casting and ceraming investment that created a surface layer (25 μm to 100 μm thick) containing porosity and diopside crystal whiskers oriented perpendicular to the surface.[16,17] This layer significantly weakened the ceramic and its removal was not indicated for reasons of fit and esthetics (becoming increasingly grey due to higher translucency).[16,17] Relatively high clinical failure rates led Corning to withdraw its support of laboratory cast Dicor in the late 1980's or early 1990's. A version for the CEREC CAD/CAM system containing a higher volume fraction of smaller crystals (70 vol%) with internal color and opacity remained available through the late 1990's (Dicor/MGC).[18]

High technology or craft art? Here dentistry tapped into the technology giant that invented glass ceramics, invented low-loss fiber optics for data communication and fabricated the mirror for the Hubble Telescope.

Non-Shrinking Ceramics III – From Beer Steins to Net-Shape Prostheses

German beer steins are complex, thin-walled ceramic objects with fanciful surface ornamentation. Crowns are complex, thin-walled ceramic objects with fanciful surface ornamentation. Steins are made by pouring dilute water-based slurries of ceramic particles into a porous gypsum mold; a process termed "slip casting". As water is transported through the mold wall ceramic particles are packed against the form. When the stein walls are sufficiently thick, excess slurry is poured off and the mold set aside to dry, allowing the split mold to be separated and the stein readied for firing.

In 1990, Heinz Clause from Vita reported on the development of a novel ceramic having the physical properties of 100% alumina that could be made to net shape.[19] Using ultrasonification and dispersing agents, a rather concentrated "slip" of alumina was made that was next brushed onto porous gypsum dies of the prepared tooth. When sufficient wall thickness was achieved any excess alumina could be carved away and margins refined. During a first firing the alumina underwent an "initial sintering" without shrinkage, involving neck formation between touching particles by surface diffusion and differential sintering of some colloidal sized particles (sub-micrometer).[20] The gypsum die shrunk away from the still porous but not-too-fragile coping that was subsequently infiltrated in a second firing with a colored high lanthanum content borosilicate glass. The lanthanum both decreased the viscosity of the glass (aiding infiltration) and increased the refractive index of the glass closer to that of the alumina (increasing translucency).[21]

Variations of this ceramic system involved the substitutions for alumina of: (1) magnesium aluminate spinel (MgAl2O4) which increased its translucency (lower refractive index than alumina) but was not as strong; and, (2) a mixture of 70% alumina and 30% transformation toughened zirconia. In-Ceram is still available today and stands as the first all-ceramic system to achieve long-term success in clinical trials, indicated for any single anterior or posterior crown.[22] It is still available by slip-casting but also by CAD/CAM machining (as will be discussed below). Vita has received numerous inquiries from industries outside of dentistry regarding their clearly "high tech" ceramic developed specifically for dental prostheses.

Non-shrinking Ceramics IV and Beyond, Prostheses Becoming Engineered Structures Closely Mimicking Nature

Dentistry also learned how to better use ceramics clinically, both for increased longevity and esthetics. For example, Dr. Ken Malament amassed an astounding clinical data-base that signaled, among other things, the survival improvement brought by bonding and use of a stiff buildup/core material.[23,24] My own contributions included applying fracture surface analysis (fractography) to identify failure origins in clinically failed crowns and three-unit fixed partial dentures.[25,26] This work was coupled to development of validated finite element models of clinical stress states at failure.[26,27]

Three-dimensional (3D) data sets of prepared teeth began to be used for prosthesis design and computer-directed machining, first in 1987 in a chairside system developed by Dr. Werner Mörmann and Marco Brandestini.[28,29] Work beginning about 1996 by Gauckler (ETH-Zürich) and Luthy (Dental Institute, Univ. Zürich) used 3D data to generate oversized parts to be machined from partially sintered zirconia blocks that would shrink to net-shape during firing.[30] Various sophisticated automated systems have extended dental laboratory machining of prostheses frameworks to alumina, zirconia and glass-ceramics.[31]

Esthetic versatility has increased as well with a variety of all-ceramic systems now vetted through clinical trials as being indicated for anterior teeth.[22] These systems offer a range of translucencies and internal color control. Handheld spectrophotometers offer advantages in shade taking and new shade systems having more uniform and rational coverage of natural tooth color space are improving traditional shade taking.[32, 33]

Summary

There has never been a period of such rapid development in dental ceramics regarding materials, processing, structural engineering and esthetics as during the past 40 years. Quite a number of the innovators are well-known within the American College of Prosthodontists. Our partnerships with industry and external scientists remain a hallmark of these innovations, as has been the case since 1774 and will likely characterize future progress. As to the question of "high tech" – no question remains!

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Chapter 7 *The Evolution of Ceramic Restorations-A Contemporary Perspective*

Ariel J. Raigrodski, DMD, MS, FACP

Ceramic materials and ceramic restorative systems have been continuously evolving, and especially over the last two decades they have made a significant impact on patient care in the prosthodontic practice. These materials were gradually incorporated for several clinical indications such as ceramic laminate veneers (CLVs), ceramic onlays and inlays, ceramic crowns, ceramic fixed partial dentures (FPDs), and ceramic implant abutments and ceramic screw-retained implant frameworks.

Over the years, increased patients' demands for metal-free tooth-colored restorations, innovations and improvements in ceramic materials, dental adhesives, computer assisted design/computer assisted manufacturing (CAD/CAM) technology in terms of both software and hardware, have all contributed to facilitating the clinical success of ceramic restorations. However, the use of these materials is not without limitations and careful treatment planning, material selection, and laboratory fabrication are all critical for enhancing clinical success and reducing the likelihood of complications.[1]

Different ceramic materials present with specific mechanical and optical properties, which may affect their selection in various clinical scenarios (such as translucent vs. discolored abutment teeth, or adequate vs. inadequate gingival

health which may preclude adequate bonding procedures) as well as some of the clinical procedures including preparation design and delivery procedures (conventional luting vs. adhesive cementation).[1] However, all ceramic materials must meet biomechanical and esthetic requirements which will ultimately affect the predictability and longevity of the prospective restoration.[2]

One of the most conservative restorative treatment modalities is the CLV. These restorations are indicated not only for treating severely discolored dentition but also for the restoration of fractured and worn dentition, as well as malformed teeth.[3]

With studies demonstrating the efficacy of bonding porcelain to enamel (as strong as natural dentition),[4] as well as the efficacy of techniques to facilitate improved bonding to dentin,[5] the use of porcelain laminate veneers may be expanded to more challenging clinical scenarios. These may include restoring endodontically treated teeth with relatively conservative endodontic access and adequate residual tooth structure or as part of full-mouth reconstructions restoring mandibular incisors (biomechanical advantage over complete coverage) or/and the worn dentition.[6] In addition to the advantage of tooth structure preservation, in certain clinical situations, the classic preparation design for a porcelain laminate veneer allows the placement of the finish line above the gingival crevice. This, in addition to having a higher probability of having the finish line placed in enamel, may facilitate the health of the dentogingival complex[7] while also promoting a perfect blend of the restoration with the underlying tooth structure taking advantage of the contact lens effect.[8]

CLVs have been fabricated either out of feldspathic porcelain or leucite reinforced feldspathic porcelain or lithium disilicate using several different techniques such as the refractory die or platinum foil, waxing and heat pressing, or CAD/CAM technology. Several retrospective clinical studies have demonstrated acceptable survival and clinical success for CLVs manufactured with different fabrication techniques and different ceramic materials with a follow-up period ranging from 5 to 16 years.[9-13] Walton's study substantiated the long-term effectiveness of his regimen while emphasizing the preservation of enamel and bonding to enamel as a key for clinical success.[13]

As with CLVs, attempting to achieve conservative patient care and functional and esthetic restorations in the posterior segments has contributed to the development and increasing use of ceramic inlays and onlays. These restorations

are fabricated mostly with either feldspathic porcelain, leucite reinforced feldspathic porcelain, or lithium disilicate, via CAD/CAM technology or via waxing and heat pressing. Although, inlay and onlay tooth preparations are considered much more conservative as compared to complete coverage crowns[14], restorations must be adequately bonded to tooth structure to reduce the likelihood of fracture and to facilitate restorations' longevity. Several clinical studies demonstrated adequate clinical success for ceramic inlays and onlays manufactured and bonded with different techniques with follow-up periods for up to 12 years in both prospective and retrospective studies. [15-18]

High-strength ceramic systems for crowns and FPDs have been available to clinicians for several decades while continuously evolving. Generally, these systems use various high-strength core materials which present with different mechanical and optical properties. These are designed and manufactured via different technologies such as waxing and heat pressing, slip-casting, and CAD/CAM technology for the fabrication of core materials as well as for the fabrication of complete contour restorations.[1] With the advent of CAD/CAM technology, various design and fabrication technologies have been developed for enhancing more consistent and more predictable restorations in terms of strength, marginal fit, adequate support for the veneering porcelain, and esthetics. Mostly these high strength copings are to be veneered with either traditional porcelain layering technique or with waxing to the core material and heat pressing. The continuous evolution in adhesive systems and composite-resin cements also plays a major role in the ability of clinicians to deliver predictably high-strength all-ceramic restorations with considerably adequate longevity.

During the past two decades several retrospective and prospective clinical studies, both from the private practice and university setting, have been published evaluating the success and longevity of ceramic crowns and ceramic FPDs in both the anterior and posterior segments. Several materials have been used in these studies with varying success for different indications while demonstrating limitations of some of these materials.

Anterior crowns made of leucite-reinforced glass-ceramic-based crowns demonstrated a high clinical success.[19] These restorations demonstrated high translucency and rely on a successful bond between the ceramic coping, the composite-resin cement and the tooth structure for strength and longevity. Copings are fabricated either using waxing and heat-pressing or CAD/CAM technology from prefabricated blanks.

Anterior and posterior crowns made of lithium disilicate glass-ceramics coping demonstrated a high success when used for fabricating crowns in the anterior and posterior segments.[20,21] These restorations are considered relatively translucent and are designed and fabricated either via waxing and heat processing or via CAD/CAM technology. Crowns can be made as either crown copings which are subsequently veneered with porcelain or as a full-contour design with subsequent staining to facilitate strength. Although the initial attempts during the late 1990's to use the material for FPDs (replacing a missing tooth up to the 1st bicuspid) have resulted in limited success, [21] a recent clinical study demonstrated a successful outcome when using this material for anterior and posterior FPDs.[22]

Glass infiltrated materials have been used with a high-temperature, sintered-alumina glass-infiltration as well as CAD/CAM technology for both crowns and for FPDs. The glass-infiltrated alumina has been used with some success for anterior and posterior crowns[23.24], as well as for three-unit anterior FPDs with limited success.[24-26] Glass-infiltrated magnesium alumina which presents with higher translucency and lesser mechanical properties than glass infiltrated alumina has been used successfully for anterior crowns exclusively.[27] Glass-infiltrated alumina with 35% partially stabilized zirconia demonstrated better mechanical properties compared to glass infiltrated alumina with high opacity.[28] Clinical studies demonstrated successful use in terms of survival of posterior FPDs with these types of frameworks.[29,30]

Densely sintered high-purity aluminum-oxide has been the first glass-free material to be designed and processed via CAD/CAM technology for semi-opaque crown copings which were later veneered with special veneering porcelain.[31] Several clinical studies have demonstrated the successful use of the material for both anterior and posterior crowns.[31-33]

The most recent ceramic core material is zirconium-dioxide**.** It is a glass-free high-strength ceramic material which was introduced for the fabrication of anterior and posterior crown copings and FPD frameworks.[2] Zirconium-dioxide infrastructures are mainly designed and processed with CAD/CAM technology.

Several zirconium-dioxide-based restorative systems are available for crowns and FPDs. Prospective clinical studies have evaluated posterior zirconium-oxide-based FPDs for up to 5 years.[34-36] Although mostly successful, one complication in some of the studies was minor veneering porcelain chipping of veneering porcelain (cohesive fracture) mainly on 1st and 2nd molars which did not require

replacement of the restorations. These may be related mainly to lack of adequate support of the veneering porcelain by the zirconium-dioxide frameworks, due to early software limitations. Also, failures have been related to incorrect firing temperatures and cooling rates because zirconium-oxide is a poor heat conductor, thus, generating internal stress within the veneering porcelain. A recent clinical study demonstrated similar survival for zirconium-dioxide-based posterior FPDs as compared to a metal-ceramic control after 3 years of follow-up.[37] Currently, zirconium-dioxide frameworks may be layered using conventional layering of feldspathic porcelain with matching coefficient of thermal expansion.[38] In addition, similar porcelain may be pressed onto to the zirconium-dioxide frameworks in the attempt to reduce cohesive chipping of the veneering porcelain which has been demonstrated in a clinical study.[39]

Finally, in the quest to facilitate soft-tissue esthetics in implant dentistry, the use of ceramics as an abutment material for implant dentistry has been suggested. Initially, aluminum-oxide cylinders have been used as preparable abutments with limited degree of success.[40] Subsequently, with the advent of zirconium-dioxide and CAD/CAM technology, zirconium-dioxide has been introduced as either preparable, semi-customized, or as CAD/CAM custom abutments. These have been introduced with different types of interfaces (zirconium-dioxide or titanium) with the implant platform as demonstrated by different systems. Advantages of zirconium-oxide as an abutment material are mainly related to its biocompatibility [41,42] as well as its ability to cause little change to the soft-tissue color, minimizing soft tissue discoloration.[43] However, there may be some limitations which may need further investigation such as the minimal required thickness of the axial walls of the abutment, abutment size as related to implant diameter, and the abutment implant platform interface and its residual effect on the implant platform.[44] In addition, the screw abutment interface may be of importance as related to the longevity of these abutments. Several clinical studies have demonstrated short term success in terms of function and esthetics with zirconium-dioxide abutments, [45-47] while others have questioned the benefits of zirconium-dioxide and ceramic restorations in implant dentistry.[48] In addition, recently, screw retained restorations with zirconium-oxide serving as both abutment and framework in one unit. While demonstrating some promise, further research is required to clarify and form guidelines as well as indications and limitations for using zirconium-dioxide for implant abutments.

In summary, different types of ceramic restorations present with many advantages for the clinician and patient. However, ceramic restorations must be carefully used for the correct indications based on scientific evidence while

understanding their advantages and limitations. Thorough understanding of the different materials available as well as the different treatment modalities with ceramic restorations is critical. Careful diagnosis of patients and sound principles of treatment planning is crucial for the longevity and success of patient care with ceramic restorations.

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Chapter 8 *Computer Based Technology in the Prosthodontic Practice*

David Guichet DDS

Introduction

The continued improvement of computer based clinical hardware and software applications has enabled the computer-based prosthodontic practice model. Today prosthodontic graduates are using electronic records, having never utilized a physical chart or film based radiographs[1, 2]. Newer capabilities like 3D digital diagnostic imaging, implant planning software and computer generated surgical guides empower prosthodontists to establish themselves as effective leaders providing optimal treatment solutions for both simple and complex restorative protocols. The purpose of this paper is to provide an update on the clinical application of computer technology currently available for the diagnostic management of prosthodontic patient.

Although the benefits are recognized, many clinicians avoid incorporating computer technology into their practices[3,4]. Some transition cautiously into the digital realm in order to benefit from the advantages that newer technology promises. An entire range of practice profiles has been described by Farman[5]. They are characterized by the degree of digital integration into the patient care setting ranging from no computer integration to completely paperless/chartless.

This change is not easy for most dentists and staff because it involves a cultural shift.

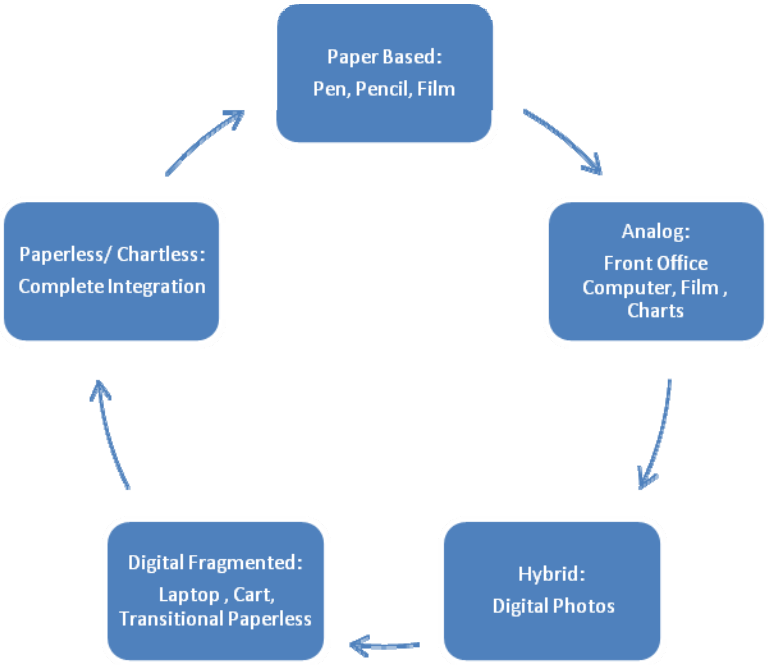

Diagram 1: The Increasing Levels of Digital Integration

Identification, Evaluation, and Infrastructure

In order to introduce new technology to a practice, it is necessary that a thorough evaluation and testing of the proposed new application takes place prior to being introduced into the practice[6]. The application must be installed and tested and key members of the staff must be trained and accountable for the training of other staff members. Additionally, once the decision is made to introduce the digital process, occasionally hardware upgrades will be required.

It is necessary to install a robust and secure network infrastructure. This includes a fileserver, hard drive backups, an uninterruptable power source, and a stable hardwired network based upon a high-speed gigabyte switch. Clinical workstations monitors must be large enough to provide effective visual access to two programs simultaneously. A 22' inch wide flat panel LED monitor on a movable arm is now considered a minimum recommended configuration. In order to achieve an ergonomic viewing position of the screen, it must be adjustable and movable for visual access to the patient, dentist and staff member when seated or standing during consultation or examination. Once the digital

infrastructure is in place, one is in a position to incorporate the clinical software application that best fits your practice's needs. It is best to make the decisions in manageable steps that allow for an effective roll out of the new software or process.

The Critical Start-up Application

When transitioning to a digital based practice, the doctor should identify a software application that would provide a valued benefit. One might call this "The Critical Start-up Application". Trends suggest that for most offices the first clinical application introduced is digital photography or digital radiography[7].

Initially the software application and data usually reside on a laptop or cart that is moved from room to room. Typically this is kept separate from the practice management database and its data is stored locally and may not be integrated with the main system data storage, backup and security protection. This approach is cost-effective but it carries risk and inefficiency. The local data stored could be lost in the event of a hard drive failure. Regular backups must be scheduled. The lack of an integrated database results in duplicates in data entry, as patient names and identifiers are required causing redundancy by adding a separate data set. Non-linked data sets typically result in bottlenecks and are limited in scale to very small practice environments. Staff members cannot access the photographs and radiographs while communicating with a patient, if they reside on a laptop or a cart. In time, a second or a third application may be identified which will serve as an incentive to build out the clinical hardware network to boost efficiency and security. Once the back office network is built, new applications can be added very effectively without additional hardware expenses.

Installation and Integration

The transition to a completely electronic record is highlighted with decisions about where information belongs[8, 9]. Doctors and staff members must be able to answer fundamental questions. "What information is needed and where does that information reside? Where is the patient's medical history and list of medications? Is the restoration on the broken tooth the one that we provided? When was the patient last seen in our office?"

When attempting to retrieve information from a physical chart, one simply accesses the information by opening the chart, turning the pages and reading. In an electronic record, information is accessed using mouse clicks which open digital pages. In a digital record the same information is available that is in a

physical chart, but it is accessible from multiple locations within the record. Additionally the information can be mined, sorted or searched. Information can be viewed by category, tooth number, date, or other variables like completed treatment or planned treatment. Therefore, questions about a patient's condition are usually simple to answer when using the electronic record. All this is possible from any computer in the office, without ever having to retrieve a physical record [10].

The Integrated Imaging Suite

It is very important to have a practice management software that is paired with good digital radiography software. The integration of the business management package with the radiography package creates an imaging foundation. That means any photographs that are included in the patient's radiographic record are tagged to the patient's digital record. For greatest efficiency an integrated imaging suite offers a practice the most stable and serviceable platform. A fully integrated system also allows you to seamlessly attach images directly to insurance claims without any third party interface.

Today most practice management software packages have partnered with digital radiographic imaging companies to create an integrated radiographic/photographic imaging suite. PracticeWorks and SoftDent have a partnership with Kodak. EagleSoft has a partnership with Schick. Dentrix has partnered with Dexis. Therefore, depending on your favorite practice management package, one might get the best support with an established partner brand. The benefit is that you will have a supported and proven system.

Additionally, as with digital radiography, digital photography can be delegated to trained staff providing the practitioner with efficient and enhanced diagnostic information. One advantage of starting with digital radiography is that the linked imaging software can serve as a foundation for the photographic images at a no additional cost.

The Key Benefits:

Efficiency and Workflow

In order to best benefit from digital technology and the efficiencies it offers, an organized workflow must be established for standard procedures such as the new patient exam. The following is a description of a new patient workflow that has proven effective in a prosthodontic group practice. It involves a standardized series of events that are managed and a new patient examination template/digital form is completed in the clinical setting. An organized workflow including

education videos, and examination templates are all utilized to manage the new patient experience while building the digital record.

Prior to seeing a new patient in the office, a treatment coordinator will extensively interview the patient and indicate the reason for the visit in the digital phone record/journal. An appointment is made in the online appointment book. Once the patient presents to the office, a receptionist scans the patient medical history and demographic information documents into the digital document center. A registered dental assistant has received the authorization to take the patient's digital panoramic radiograph and digital extraoral and intraoral photographs. Once digital imaging has been completed the patient is given a walking tour of the practice and then seated. While uploading the photographic images to the digital record the patient watches a six-minute online Florida Probe Periodontal educational video. Then the patient's photographs and radiographs are opened up onto the 22" inch LCD while and the patient interview begins. An examination template is launched from the digital chart which prompts the RDA through a series of questions about the patient. The patient sees their photographs on the monitor while the dental assistant discusses the patient's chief concerns and reviews the patient's digitally scanned medical history. The dentist is then introduced to the patient while the dental assistant repeats the patient's entire pertinent profile, in the presence of the patient while the dentist is reviewing the photographs and radiographs. Within moments the dentist has been introduced to high quality digital information about that patient with a minimum of time invested. The universal application of an electronic health record is a primary focus of the federal government to be established by 2015 and therefore a digital platform will ultimately be necessary.

Patient Education and Treatment Planning

The doctor reviews the radiographs and photographs while making treatment planning notes. The Dexis alert functions are used to annotate areas of concern on the intraoral radiographs(FMX). While the periodontal exam is being performed, The Florida Probe software gives audible warnings that inform the patient. Then the restorative charting is completed while correlating the diagnostic input with the patient's condition in order to develop an appropriate treatment plan that directly addresses the patient's concerns. Launching 3d software assists in clarifying the steps, benefits, alternatives and possible limitations of the treatment. Pulling up photographs of other patients treated with similar needs is a powerful prognostic tool. Then the patient is transitioned to the treatment coordinator who is prepared to discuss the benefits of a comprehensive approach, staging options, and costs. He/she can access all the

patient's digital information and a library of completed treatments, using a tablet PC or Laptop to reinforce treatment acceptance. If the dentist does not have a library of their completed work, patient educational software packages can be accessed, such as Consult-PRO, Implant Docs, BiteFX ™, Casey, Dentrix Presenter or Guru.

Education modules are linked to the patient's chart and stored as a permanent part of the digital record. Annotations are also stored on the image and are have a digitally sealed, time-stamped image of the video vignette and the notes from that day. These entries serve as very powerful testament to the patient's digitally signed comprehensive informed consent. Other steps like digitally signed oral sedation consent and pharmaceutical prescriptions are recorded and printed directly from the treatment planning and pharmaceutical modules and are permanently stored as a part of the electronic record. Physical printouts of the plan and corresponding consents and prescriptions are given to the patient who is then appointed in the online appointment book according to the proposed treatment sequence in the digital journal.

If the treatment plan involves a number of implants, both the 2d and the 3d CBCT visualization software add-ons have a digital library of major manufacturers' implants to clarify appropriate sizes and shapes. The radiograph is calibrated according to the magnification factor for the given image and is then used as a guideline for treatment possibilities. Implants from the library set into the panoramic or cone beam radiograph can serve as a reminder of the intended plan and serve as a record of the conversation with the patient. Collaborative implant treatment planning software also allows the colleagues as well as the patient to visualize the position of the mandibular nerve, the sinuses, the available bone, the various sizes and shapes of implants that are most appropriate for the given situation.

Improved Clinical Results

Once the digital infrastructure is in place, applications can be added to the practice very cost-effectively. For example, if in one's community a radiographic laboratory purchases a cone beam scanner, one can purchase 3D implant imaging software to complement the cone beam data in order to view and edit those files. Some 3D software, such as Facilitate View can be downloaded free from the Materialise/Astra Facilitate Web site.

Virtual access of the digital radiography and cone beam technology facilitates implant treatment decisions. Interdisciplinary team members may collaborate on

CBCT data prior to performing procedures. The position, the depth, inclination and orientation that a very highly skilled surgeon may be able to do only after a great deal of training, the younger surgeon may be able to accomplish with a flatter learning curve and with a minimum elevation of flaps. Using web-based password protected file transfer services, like yousendit.com, transferbigfiles.com or sendbigfiles.com, CBCT labs may transfer patient data bypassing physical mail and physical CD data storage.

Remote access software, like GoToMyPC.com or Logmein.com, is an unexpected advantage of applications serving the digital office. Via communication over the Internet, one can access the schedule and patient clinical data from anywhere. One can be at home and in moments log in to look at the patient schedule, review radiographs/treatment plans, prescriptions, laboratory or implant ordering needs.

An online Electronic Health record that is password protected, HIPPA compliant, and secure also enables interdisciplinary team collaboration. TeamLinx.com or USHealthRecord.com an application service provider offers interdisciplinary team members and study group members access to an interdisciplinary Electronic Health Record for complex treatment sequencing and treatment coordination. Diagnostic coding with ICD9 and ADA Codes may also allow for data mining of the electronic records. This might be used to revealing information about patient risk or treatment prognosis from similarly treated patients. The electronic record
will be the way of the future so any investment in digital technology now will likely serve as a platform for the future.

Overcoming Challenges

The more one transfers their practice processes into digital realm, the more dependent one becomes upon maintaining and troubleshooting their digital infrastructure. It is of critical importance to have access to a well disciplined daily backup procedure and to use industry standard processes. Practice management software companies have access to many service technicians who apply industry standard processes to insure that your system is functional and secure.

Identifying technologically savvy staff members is key to performing data backups and troubleshooting when problems arise. If a clinical workstation goes down, a wireless laptop can be used effectively to keep the team running. A free software service included with Microsoft Windows called Remote Desktop

allows the laptop to access another functional computer in the office until a solution to the original problem can be applied. Remote Desktop can be installed quickly.

Brand name vendors include online assistance where many problems can be addressed efficiently with an expert technician via the web. In the technology world there is a constant leapfrogging of hardware performance and memory hungry features that software developers offer. New software upgrades may make older computers slow to a crawl necessitating upgrades. Realizing that these possible slowdowns occur often necessitates updating older hardware workstations. Two approaches to hardware are commonly used. One is to purchase all the computers in the system at the same time and limit the upgrades. An alternative approach is to have high priority computers workstations and use the newest computers there, with a trickle down of the older computers for non-patient purposes.

Conclusion

The digital dental practice requires staff training, infrastructure and clinical software. Customized clinical software can improve communication within the office team, increase patient acceptance of treatment plans, make staff more productive, allow access to patient records from anywhere and enable better and faster delivery of care. Patients expect today's dental office team to function with the latest technology. They want access to online information about your practice and to be able to download patient forms, such as those for their health history, financial information and appointment dates. All of this is possible with today's technological advances in clinical software and a secure computer hardware infrastructure.

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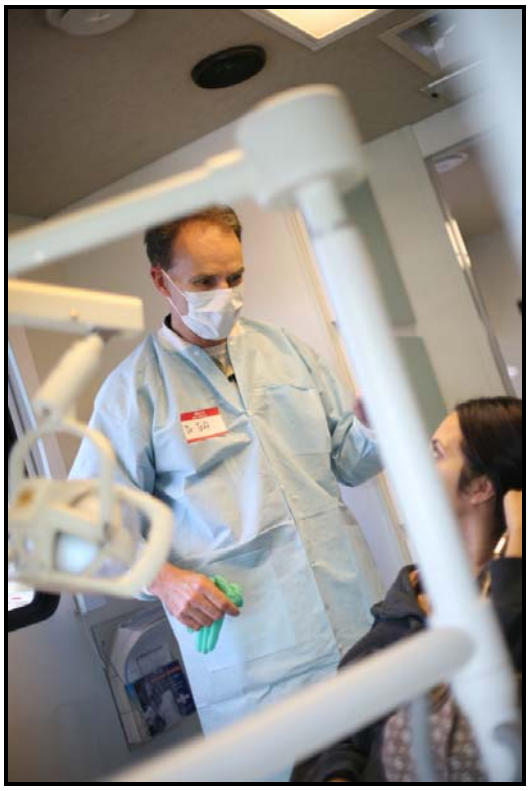

Chapter 9 *Digital Technology in Prosthodontics – Historical and Future Perspectives*

David Gratton, DDS, MS

Since the dawn of the new millennium, a plethora of new digital prosthodontic technologies have been developed to enhance patient therapies. Conventional dental therapies have been augmented or replaced with new materials and technologies that a decade ago were mostly a dream or at best, still on the drawing table. Every aspect of prosthodontic dentistry has been affected, from increased efficiency and accuracy chairside and in the laboratory to high-strength, long-lasting, esthetically pleasing prostheses that meet ever-heightening patient demands.

The purpose of this discussion is to outline the relevant technologies that are directly and indirectly involved with prosthesis manufacture and delivery. Many of these technologies address the fabrication of dental prostheses and can be broadly categorized as chairside systems, laboratory based systems, and centralized industrial systems. The chairside systems can be further classified as chairside digital impression systems and chairside digital impression/milling

systems. The laboratory systems typically scan stone dies, although some systems now claim the ability to scan conventional impressions. Single and multi-unit prostheses are typically milled using 3, 4, or 5-axis milling engines. The large centralized industrialized systems are focused on automation and production. The boundaries between these broad categories are becoming blurred, as market forces are demanding the convenient exchange of digital data between systems and platforms. The advantages of using prosthodontic CAD/CAM technologies for patient care include: introduction of new materials, reduced labor involvement, cost effectiveness, and quality control.[1]

Of the four pioneering dental CAD/CAM systems – the French System developed by Dr. Duret in 1971,[2] the Swiss System developed by Dr. Mormann,[3] the Minnesota System,[4] and the Swedish System developed by Dr. Andersson[5] during the 1980s –the Swiss System known today as the CEREC System and the Swedish System known today as the Procera System continue as viable systems. The CEREC 1 introduced to dentistry in 1985 was unique in its ability to take a digital intraoral impression, create a prosthesis using CAD software, and then mill the prosthesis chairside.[6] Currently, in the North American market there exist four chairside systems, two of which also allow chairside manufacturing of prostheses (CEREC, Sirona Dental Systems GmbH, Bensheim, Germany and E4D, D4D Technologies, Richardson, TX, USA) and two of which only allow for the digital impressions (iTero, Cadent Ltd, Or Yehunda, Israel and Lava COS, 3M ESPE, St. Paul MN, USA).

The CEREC AC system scanner uses a visible blue light from light emitting diodes (LEDs). The scanner has a working focal length of 5-15 mm. A series of still images is captured of the powdered preparation. The restoration is then designed and milled or casts can be fabricated through stereolithography. The E4D uses a red laser light oscillating at 20,000 Hz to capture images of the preparation. Powder is typically required . The restoration is designed and sent to the milling unit for fabrication. The Lava C.O.S. scanner employs 192 LEDs and 22 lenses with a pulsating blue light to capture video using active wavefront sampling technology. Light powdering is required. Casts are created using stereolithography. The iTero system (no powder needed) uses a laser light source and parallel confocal technology to capture the digital data. Casts are then milled on a 5-axis milling engine for use in traditional laboratory techniques. However, the data can also be exported to a CAD/CAM system for the fabrication of a framework or full contour prosthesis.

Inlays and onlays fabricated from feldspathic ceramic using the CEREC system have demonstrated an 88.7% survival rate probability for up to 17 years.[7] Crowns manufactured from feldspar ceramic blocks with the CEREC system have shown a cumulative Kaplan-Meier survival of 97.0% and 94.6% for premolars and molars respectively.[8]

The marginal fit of crowns and fixed partial dentures fabricated from laboratory based CAD/CAM has been the subject of several in vitro investigations. One such studied assessed the marginal fit of four-unit zirconium oxide fixed partial dentures pre- and post-veneer porcelain firings. Three systems were evaluated: Everest (KaVo Dental GmbH, Biberach, DE), Procera (Nobel Biocare Holding AG, Zurich-Flughafen, SUI), and Lava (3M ESPE 3M ESPE, St. Paul MN, USA) at three time periods: before porcelain firing, after porcelain firing, and after glaze firing. The mean vertical marginal gap in micrometers for the Everest system were: 63.37, 65.34, and 65.49; for the Lava system were: 46.30, 46.79, and 47.28; for the Procera system were: 61.08, 62.46, and 63.46 for the respective times. The authors concluded that the three zirconium-oxide-based ceramic CAD/CAM systems achieved comparable and acceptable marginal fit, noting that the gap measurements of Lava system were statistically smaller than those for the Everest and Procera systems. The marginal fit of the zirconium-oxide-based ceramic fixed partial dentures remained constant after the porcelain firing cycles and the glaze cycles.[9]

Digital occlusal recording devices such as the T-Scan III® (Tekscan, South Boston, MA, USA) have been used to evaluate the distribution of time and force in occlusal balance and can be useful as a diagnostic screening method for occlusal stability in intercuspal position.[10] In the computer aided design process for creating a crown, sophisticated mathematical algorithms allow for patient specific feature-based adjustments of library tooth morphology provided that sufficient data has been collected of the proximal, opposing and contralateral teeth. Through the use of the NURBS (non-uniform rational B-spline) surface and a set of B-spline curves, global features such as crown height and crown width are modified first, then specific occlusal features such as cusps, fossa, and marginal ridges are adjusted to finalize the crown design.[11] This concept of the "biogeneric tooth" has been shown to offer a significantly greater degree of crown morphology naturalness and was significantly quicker in designing partial crowns compared with conventional software. It was concluded that the biogeneric tooth model generates occlusal morphology of partial crowns in a fully automated process with higher naturalness compared with conventional interactive CAD software.[12] In consideration of the dynamic movements of the

mandible, contemporary dental CAD software systems are beginning to incorporate virtual articulation[13] [14]and utilize dynamic motion capture to optimize the CAD design such that the prosthesis will functional within the constraints of the stomatognathic system.[15]

Spectrophotometers and colorimeters have been developed to aid the clinician in taking a correct shade. Comparing the Vita Easyshade (Vident, Brea, CA, USA) to conventional visual means of shade selection, it has been noted that the spectrophotometer method resulted in a five times more likely match to the original shade color. However, it was concluded that the system does not solve all the problems inherent in shade selection and that the system requires further refinement.[16] Crowns fabricated using dedicated spectrophotometric techniques have been shown to have a significantly better color match and decreased rate of rejection as a result of color discrepancy compared with crowns produced using conventional shade selection methodologies.[17] As these computer assisted methods of shade selection continue to be validated clinically, importing this data into dental CAD/CAM systems will allow precise positioning of milled prostheses from multicolored ceramic blocks and ultimately the ability to layer ceramic powders through the "ink jet" principle or laser sintering.

CAD/CAM technology is prevalent within implant prosthodontics, encompassing the design and fabrication of surgical guides,[18] design and fabrication of custom abutments and frameworks, and even surgical guidance during implant placement.[19]The blending of cone beam computed tomography data of the osseous structures and optical scans of intraoral hard and soft tissues (taken with either an intraoral scanner or a lab based gypsum scanner) allow for not only a CAD/CAM surgical guide, but also the design and milling of the definitive abutment presurgery.[20] In a systematic review investigating the existing evidence from human clinical trials involving prosthetic implant CAD/CAM technology, only five of the 885 articles reviewed met the defined search criteria – three for CAD/CAM framework and two for CAD/CAM abutments. The authors concluded that the preliminary proof of concept for CAD/CAM implant frameworks and abutments had been established. However, the studies were too preliminary and underpowered to generate relevant conclusions as to the long term success and survival of CAD/CAM frameworks and abutments.[21]

With any new technology there is a sequence of consumer adopters: early adopters, early majority, late majority, and laggards.[22] The early adopters desire more technology accepting difficulty in operation, basic esthetics, and flux, while

the late adopters demand efficiency, pleasure and convenience. This is realized through human-centered product development and design.[23] Currently, digital prosthodontic technologies are transitioning through this later phase of product development, becoming easier to learn and adapt to clinical practice, enhancing patient comfort, and providing for efficient prosthesis fabrication workflow.

Through the leadership of current American College of Prosthodontists (ACP) President Dr. Lyndon Cooper and the American College of Prosthodontists Education Foundation (ACPEF) a symposium centered on digital technologies pertaining to Prosthodontics was convened at the University of North Carolina in January 2008.[24] This gathering of key Prosthodontic opinion leaders and digital technology industry leaders explored the current and emerging prosthodontic technologies. Presentations and discussions focused on five topics: Diagnostic Imaging, Intraoral Data Capture, Custom Implant Abutment/Prostheses, Prosthesis Fabrication, and Treatment Planning Software. Members of focused break out sessions deliberated on four key questions: What can the ACP do to promote technology transfer in dental schools and private practice? What will the working model be between laboratories, dentists, and companies? What research needs should be promoted? What is the role of digital diagnostics in prosthodontics and how should it be integrated? Strategies were discussed that could aid in the adoption of these digital technologies by Prosthodontists and general dentists, such that Prosthodontists are recognized as the leaders in digital dentistry. Answers to an audience response questionnaire highlighted that considerable effort will be required to close the gap between what is perceived to be possible, what is possible today, and what will be possible in future. When asked, "When will digital impressions replace conventional methods for master impressions?", thirty-four percent of the participants responded within 3-5 years and 53% of respondents indicated within 5-10 years; however, when asked, "When will stone and plaster become obsolete in the dental laboratory?", forty-four percent of respondents indicated never. If 87% of respondents indicated that digital intra-oral impression techniques would replace current analog techniques, what are the 44% of respondents who indicated that stone and plaster would never become obsolete using the stone and plaster for? The conference concluded with this purposeful remark from Dr. Cooper: "Prosthodontists are innovation leaders and have formed new partnerships in the rapidly changing technology industry. Together we will bring clinical improvements to the dental community by careful testing and evaluation, documentation and, especially, education."

While thousands of dentists and technicians have integrated digital technologies into their practices and laboratories over the past decade, thousands more have yet to take more than a first step. Thus, today's prosthodontists share a great responsibility, and a greater privilege, to lead the digital dentistry revolution both in research and in practice, and to continue to move dreams to the drawing table, and then to reality.

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