TITANIUM VS. ZIRCONIA FULL-ARCH IMPLANT-SUPPORTED FIXED PROSTHESES: A COMPARISON OF PLAQUE ACCUMULATION

A Thesis

by

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Submitted to the Office of Graduate and Professional Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

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May 2018

Major Subject: Oral Biology

ABSTRACT

The purpose of this prospective, longitudinal, descriptive clinical study is to investigate the plaque accumulation and soft tissue inflammation in maxillary full-arch implant-supported fixed prostheses (FIFP) fabricated with either Titanium (Ti) or Monolithic Zirconia (Zr).

Materials and Methods: Twenty healthy patients participated in the study and were categorized by the type of FIFP in the maxilla (Ti vs. Zr). The prosthesis had to be in function for at least three months and patients had to be enrolled in a 3-month interval maintenance program.

Patients were required to attend three maintenance appointments, scheduled at 3-month intervals. Information collected at each appointment, included: 1) Standardized photograph to record Plaque Area Index (PAI) of the intaglio surface of the prosthesis, 2) Clinical parameters, including: modified Plaque Index (mPI), modified Bleeding Index (mBI), implant mobility (MOB), probing depths ≥5mm (PD), suppuration (SUP), keratinized tissue band ≥2mm (KT), and 3) Intraoral photograph of the maxillary arch without the prosthesis to evaluate soft tissue erythema.

Results: MOB was not present at any implant at any time point. SUP could not be analyzed because it was an infrequent finding. Both groups exhibited significant increases in mBI over time. No significant differences were observed for PD between the groups at any time point. Implants in the Ti group had significantly higher KT values than the Zr group; levels remained constant over time for both groups. FIFP in the Zr group had slightly lower PAI levels than the Ti group. The PAI in the Zr group significantly decreased

over time (p=0.035), the PAI in the Ti group remained constant (p=0.45). Higher PAI levels were correlated with increased levels of soft tissue erythema; both groups had a significant decrease in erythema values over time (p=0.04).

Conclusion: Zr FIFPs displayed a significant decrease in plaque accumulation after periodic maintenance procedures and oral hygiene instructions. Ti FIFPs had significantly higher plaque levels than Zr at all time points and did not respond to maintenance and oral hygiene measures. These findings suggest that zirconia responds well to plaque control measures, while attempts at plaque control on titanium may prove to be quite difficult.

ACKNOWLEDGEMENTS

I would like to thank my committee members, Drs. Rossmann, Griffiths, Diekwisch, and Gonzalez for their guidance and support throughout the course of this research. I would like to thank Dr. Triplett for his kind help to review this work. Thank you to Dr. Steve Harrel for serving as an expert consultant and examiner. I would also like to thank Dr. Mirali Pandya for her guidance with the use of Image-J software.

Thanks to the staff at the Department of Periodontics for their assistance in clinical appointments and patient care. Thanks to the Center for Maxillofacial Prosthodontics under Dr. Jorge Gonzalez' direction, for allowing an invitation to their patients to participate in this study.

Thanks to my parents and parents-in-law for their encouragement and support. Finally, infinite thanks to my wife for her patience, love, encouragement and company through this journey.

CONTRIBUTORS AND FUNDING SOURCES

This work was supervised by a dissertation committee consisting of Dr. Jeffrey Rossmann, Dr. Garth Griffiths, and Dr. Thomas Diekwisch of the Department of Periodontics; Dr. Jorge Gonzalez and Dr. Gilbert Triplett of the Department of Oral and Maxillofacial Surgery. Dr. Daisha Cipher completed the statistical analysis. All work for the dissertation was completed independently by the student.

This project was funded internally by the standard research grant for residents in the Department of Graduate Periodontics, Texas A&M College of Dentistry. Bio statistical consultation was partially funded by the Baker Trust Fund of the Department of Periodontics. No external financial support was used to complete this project.

NOMENCLATURE

FIFP	Full-Arch Implant-Supported Fixed Prosthesis
FIFP-Ti	Full-Arch Implant-Supported Fixed Prosthesis - Titanium
FIFP-Zr	Full-Arch Implant-Supported Fixed Prosthesis - Zirconia
PMMA	Polymethyl-methacrylate
A/P spread	Antero-posterior spread
TAMUCOD	Texas A&M College of Dentistry
PAI	Plaque Area Index
mPII	Modified Plaque Index
mBI	Modified Bleeding Index
MOB	Implant Mobility
PD	Implant Probing Depth
SUP	Suppuration
KT	Keratinized Tissue
BOP	Bleeding on probing
PD	Probing depth
PFM	Porcelain fused to metal
CAD/CAM	Computer aided design/Computer aided manufacture
T0	Visit #1
T1	Visit #2
T2	Visit #3
OHI	Oral hygiene instruction

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1. INTRODUCTION AND LITERATURE REVIEW

Need for complete teeth replacement

The masticatory system is an essential part of the human body since it is the first component of a complete and efficient digestive process. A full complement of teeth is important for the mental and physical well-being of the individual since teeth have a direct impact on esthetics, function, and speech.

The masticatory system is formed by the organs and structures primarily functioning during the process of chewing. The masticatory system includes teeth and their supporting structures, craniomandibular articulations, the mandible, accessory musculature, the tongue, lips, cheeks, the oral mucosa, and the associated neurologic complex.[1]

There are several factors that can affect the masticatory system and cause tooth loss, including pathology, caries, periodontal disease, trauma, iatrogenic factors, tooth eruption problems, prosthetic indications, orthodontics, and occlusal problems.[2, 3] In patients younger than 50 years of age, the main reason for tooth extraction is caries. However, in patients older than 50 years, the main reason is periodontal disease.[3]

A patient is considered edentulous when all teeth are lost. Edentulism is a chronic disability that affects the patient's quality of life. Due to limited chewing ability and limited food choices, the digestive process is altered, and nutrient intake is compromised.[4] Speech and esthetics are greatly compromised resulting in limited ability to socialize.[5] The prevalence of edentulism in the elderly population worldwide is extremely high, ranging from 20% to 60%.[4]

Although the percentage of edentulous patients has declined by 10% in western countries in the last decade, a higher number of patients will need full-arch tooth replacement. This is due to the population boom in the United States, increasing from 33.6 million in 1991 to 37.9 million in 2020.[6]

There are different methods to replace missing teeth, which is determined based on the type of edentulism (partial or complete). Treatment options for the replacement of multiple missing teeth can be classified into two main categories: removable and fixed. The prosthetic device that replaces missing teeth is referred to as a denture, which can be a partial denture (for partially edentulous patients) or a complete denture (for fully edentulous patients).[7]

Removable partial dentures (RPD) can be supported by the natural remaining teeth and by the soft tissues in the edentulous areas.[8] Removable complete dentures are supported by the edentulous alveolar ridge and rest on the soft tissue.

Both partial and complete dentures need to be removed from the mouth daily to allow for proper hygiene procedures. This is necessary in order to prevent fungal infections of the intraoral soft tissues and to prevent various soft tissue lesions.[8, 9]

Fixed partial dentures (FPD) can be supported by natural teeth or by osseointegrated implants.[10] FPDs cannot be removed since they are fixated to the supporting teeth or implants by either luting agents or screws.[11] When a single tooth is missing, the most common treatment options are an FPD or a single dental implant. FPDs are sometimes preferred over single dental implants since there is no need for a surgical procedure and there is no need to wait for the implant to osseointegrate.[11, 12]

Fixed complete dentures, as opposed to removable complete dentures, are supported by osseointegrated dental implants. Dental implants are used for fixed complete dentures when the patient does not possess any natural teeth to serve as denture abutments.

Removable complete dentures offer a cost-effective treatment option for patients that need complete tooth replacement in one or both arches. These prostheses are traditionally fabricated utilizing a base of gingiva-colored polymethyl-methacrylate (PMMA) resin that provides full coverage of the edentulous arch. Contemporary Computer Aided Design/Computer Aided Manufacture (CAD/CAM) methods and new resins have also been utilized for denture base fabrication in the past few years.[13] Prosthetic teeth are mechanically and chemically bonded to the aforementioned acrylic base. Prosthetic teeth provide the function and aesthetics that mimic the natural dentition.[1, 9] These prosthetic denture teeth are usually fabricated with PMMA resin, composite resin or porcelain.[14] Composite resin is currently the most widely used material due to its favorable mechanical properties, wear resistance, and esthetic properties.[15]

Adequate stability and retention on the edentulous ridge is one of the main goals in the fabrication of removable complete dentures.[16] However, due to mechanical limitations, removable complete dentures are often lacking these key properties. This can lead to complications, including lesions of the oral mucosa, chewing inability, speech impediment, and inability to socialize.[7]

Most patients must resort to denture adhesives in order to improve the retention properties of their removable complete dentures.[16] A better long-term solution, which overcomes these denture retention issues entails the use of dental implants.

Brief history of dental implants

In 1952, Dr. Per Ingvar Brånemark, an orthopedic surgeon from Sweden, discovered osseointegration, which is defined as a firm, intimate, and lasting connection between the implant and the vital host bone.[17]

Dr. Brånemark and his team were studying the function of nutritive capillaries in bone marrow by utilizing a vital microscopic chamber. These titanium chambers were anchored to the bone of rabbits' fibulae and pierced the covering soft tissues. It was discovered that these optical chambers could not be removed from the adjacent bone once they had healed, which suggested the possibility of osseointegration.[18]

After these observations, Dr. Brånemark and his team performed studies on the healing and stability of titanium tooth root implants, and they documented the long-term stability of these devices in dog studies.

The current definition of osseointegration is: "1. the apparent direct attachment or connection of osseous tissue to an inert, alloplastic material without intervening fibrous connective tissue; 2. the process and resultant apparent direct connection of an exogenous material's surface and the host bone tissues, without intervening fibrous connective tissue present; 3. the interface between alloplastic materials and bone."[1] Osseointegration implies a direct contact of the bone with the implant material (currently used titanium alloys). Dr. Leventhal described the applications of titanium in surgery in 1951[19] after he observed multiple studies by Dr. Brånemark and his collaborators.

Titanium is not the only material that has been used to fabricate dental implants. In human history, tooth replacement implants has been documented since the Mayan

culture where pieces of shell were used to replace mandibular teeth around 600 AD.[20] Maggiolo implanted a gold tube into a fresh extraction socket in 1809 in France, which is considered the first modern dental implant. The soft tissue around Maggiolo's implant showed a considerable inflammatory process. While these implants were not successful for long term use, they shaped the path for root-form implants.[21]

In 1885, Dr. J.M. Younger implanted dry human teeth from cadavers into patients' jaws after surgically creating a socket to receive the tooth.[21]

By 1910, Dr. Greenfield had designed a new root-form implant system. He used trephines to create a recipient site and utilized hollow cylinders the same size as the trephine. These cylinders were fabricated from iridio-platinum wire with the upper portion made of gold.[21, 22]

The following attempt to find a material that could be used for implants was by Drs. Venable and Stuck, who used Vitallium (chrome-cobalt alloy) to fabricate screw-form implants. These were placed in fresh extraction sockets and they revealed the first true histologic evidence of bone growth around a metallic implant. Unfortunately, these devices failed within a short period of time due to infection and extreme inflammatory responses to this type of metal.[20, 21]

In 1941, Dr. Gustav Dahl designed the subperiosteal implants in Sweden, which were designed for completely edentulous patients. These implants consisted of a metal structure that was custom-fabricated based on a cast model of the patient's bony architecture. These were surgically placed under the periosteum and over the bone with vertical components that protruded through the soft tissue. These vertical components were designed to attach to the tooth-replacement prosthesis. Subperiosteal implants had

acceptable five-year results, but poor long term success. 50% to 60% of these implants failed within 15 years, which led to removal of most of these implants and abandonment of this treatment option. Some of the most commonly observed issues with subperiosteal implants were infections, implant exposures, and localized or extensive bone resorption.[21, 23]

In the late 1940's, Manlio Formiggini presented a spiral implant fabricated from tantalum. This implant contained a screw hole, which allowed for attachment of the prosthetic component in the coronal section. Formiggini is considered by many as the "Father of Modern Implantology."[20, 24]

In the early 1960's, Chercheve introduced a double-helical spiral implant made of cobalt-chromium-molybdenum. Along with this unique implant design, Chercheve developed an implant placement system that consisted of two different diameters of bone taps and a hand ratchet for implant insertion.[20, 22]

In 1967, another advance in implant dentistry was made by Leonard Linkow. He developed a self-tapping implant that contained lateral vents designed for the ingrowth of bone. Linkow first utilized chrome-cobalt and stainless steel, but he later used commercially pure titanium due to the successes of Dr. Brånemark's research. Linkow also designed the endosseous blade implants that were successfully used in sites where bone volume was limited. The Linkow blade implants allowed for implant placement in sites where it would have not been possible to place a regular screw-shaped implant. He designed implants with 34 different shapes to accommodate different anatomical regions of the jaws.[22, 24]

In 1981, Adell, Brånemark and their team (Lekholm and Rockler) published their 15-year outcomes from the treatment of edentulous patients utilizing osseointegrated titanium implants. They followed 2,768 implants in 410 jaws of 371 patients.[17] Their typical protocol was to surgically place six dental implants in the region between the mental foramina for the mandible or between the anterior walls of the maxillary sinuses for the maxilla. A specific sequence was used for their osteotomies, which entailed incremental diameter burs and specific rotation speeds based on the type of bone encountered. After the implants were inserted into the bone, cover screws were placed to protect the implant platforms, and the soft tissue was sutured over the implants. This was known as the submerged technique. After a healing period of three to four months for the mandible or five to six months for the maxilla, an incision was made to replace the cover screws with transmucosal abutments. The entire surgical phase was carried out under sterile conditions and only by trained operators.[17, 25]

The prosthetic phase of the treatment started two weeks after implant uncovery and transmucosal healing abutment connection. The restorative dentist made impressions of the implants and edentulous ridges utilizing special impression copings. Also, a temporary bridge was fabricated using acrylic resin and a metallic reinforcement bar. The permanent bridge was fabricated after 9-24 months. The final bridge was designed to attach to all implants in the edentulous arch. This bridge had a metal framework with gold cylinders that screwed into the implants. On top of this metal framework was acrylic denture teeth and acrylic resin, which provided a natural-looking smile, consisting of both teeth and their surrounding soft tissue. The occlusion was adjusted by selective grinding on this bridge as needed. The pontic design in these

bridges included “peri-abutment” spaces, which gave access for hygiene devices between the bridge and the patient’s underlying soft tissue. The bridge design was adapted for each patient and in every case included a noble alloy framework with acrylic resin teeth.[25, 26]

In a 15-year follow up study, Adell *et al* reported an 81% success rate for implants installed in the maxilla, 91% success for implants in the mandible, and 100% continuous bridge stability. The authors also reported a mean bone loss of 1.5 millimeters during the initial healing period, which was the first year after implant uncovery. After the first year, the authors observed only 0.1 mm of marginal bone loss per year.[17]

In 1982, the Toronto Conference was held, where the long-term results on implant survival were presented and the concept of osseointegration was explained. This conference was a breakthrough for the dental implant industry since representatives of all major dental schools in North America were now exposed to the work done by Brånemark and his team. This resulted in a widespread knowledge and use of osseointegrated implants.[27]

Design and fabrication of complete fixed implant dentures

Since the Toronto Conference, implant dentistry has drastically evolved, allowing for a wide variety of methods to replace missing teeth. New advances in implantology allow for a predictable replacement of one tooth, multiple teeth, or an entire arch of teeth. In 1993, Zarb *et al* described, for the first time, the use of osseointegrated dental implants to restore the partially missing dentition, specifically in the maxillary and mandibular anterior regions. They observed a 91.5% success rate for implants that had been in

function for a period of two to eight years.[28] In a similar manner, Jemt and Lekholm reported their five-year results for patients that had implant prostheses in partially-edentulous posterior regions. These patients had a cumulative success rate of 97.2% for implants and 100% for prostheses.[29]

The design of the original implant developed by Dr. Brånemark has also evolved in several ways, including different connections between the implants and abutments, different titanium alloys, and different implant surface treatments.[30] The implant originally designed by Dr. Brånemark had a smooth machined surface. However, the implant surface has been modified in a variety of ways in the past 20 years. Some of these modifications, known as surface treatments, include titanium plasma spray, anodizing, acid etching, sandblasting, and hydroxyapatite coating. This modification of the implant surface increases the surface area and texture, thereby providing improved cell affinity. This has allowed for a decrease in the osseointegration period from 6 months to as little as 6 weeks for some implant systems.[20, 30]

Dental materials for implant restorations have also evolved, especially in the last 15 years. Implant restorations provided by Brånemark and his team were fabricated in two parts: a metal framework was casted utilizing a silver-palladium alloy and denture teeth were attached to this framework using pink acrylic resin. This framework was tested for a passive fit on the transmucosal abutments that were connected to the implants. The metal framework was designed in one piece to connect to all of the implants and provide a distal cantilever extension in the molar region. If misfit of the metal framework was observed, it was sectioned, reassembled, and soldered in the correct position. Once the metal framework was adjusted, denture teeth were set-up over the framework, and pink

acrylic resin (same acrylic resin that is used to fabricate removable dentures) was used to fixate the teeth on the framework. The pink acrylic also provided an esthetic replacement for the missing ridge volume. The prosthesis was then fixed on the implant abutments utilizing screws so it could be electively removed by the clinician for maintenance and repair procedures. This prosthesis was also known as a “Toronto” bridge, because it was presented during the Toronto Conference. Another common name given to this restoration is “hybrid prosthesis,” due to the different nature of the materials utilized to fabricate it.[26, 27, 31]

Zarb *et al* reported on the complications observed in 49 arches in a period of four to nine years after loading of the prostheses. Prosthodontic complications included abutment screw fractures, gold prosthetic screw fractures, and framework fractures. Mechanical complications included framework misfit, extensive cantilever, lack of adequate framework thickness and poor alloy selection.[32, 33] Jemt and Lie studied the accuracy of casted gold frameworks for maxillary and mandibular implant supported prostheses. They observed a mean angular distortion of the cylinders of 51 μm for the mandible and 70 μm for the maxilla. It was hypothesized that these discrepancies could induce stress to the implant components and cause biomechanical complications. The authors claimed that more distortion was observed for maxillary prostheses due to the position and angulation of the implants.[34] To help alleviate these issues, Parel reported a modified casting technique to achieve accurate framework fit and therefore prevent these complications seen with framework misfit.[35]

In the mid 1990’s, the development of CAD/CAM and milling technologies by Procera® made it possible to mill these frameworks from a solid block of metal using

computer numerical control (CNC) machines. Grade 2 Titanium became the metal of choice for fabrication of these frameworks due to its mechanical properties, biocompatibility, compatibility with the implant components (same material), low cost (compared to precious metals), and increased precision in fit. This computer-aided process for metal framework fabrication eliminates the expansion and contraction that occurs during the casting technique since it is milled from a solid block of material. Riedy *et al* observed significant differences in the precision of fit between machined titanium frameworks and casted frameworks. The titanium framework displayed superior accuracy.[36] In an *in vitro* study, Takahashi *et al* compared the fit of 19 frameworks fabricated with either machined titanium or a casted gold alloy. The authors found that titanium frameworks provided a significantly better fit than casted frameworks.[37]

Another advantage to the machined framework is the availability of a digital file, which allows for re-manufacturing of the framework if it needs to be replaced.

There are numerous metal framework designs for hybrid prostheses, which can be classified into two main categories: 1) framework designed with a larger bulk of metal and less acrylic resin; and 2) those that have less volume of metal and more acrylic resin, known as the wrap around.[38] If the first approach is selected, the acrylic resin is used only for bonding the prosthetic teeth and mechanically engaging the framework. The lingual/palatal and intaglio surfaces of the prosthesis are metal and the acrylic is located only on the buccal and occlusal surfaces around the teeth. This design entails a prosthesis-ridge interface that is made up of metal. The second approach is designed utilizing a minimal volume of metal, generally located in the inner portion of the prosthesis. Retentive elements such as beads, pins, or grooves can be incorporated to improve

mechanical retention to the acrylic resin. The acrylic resin wraps around the metal framework completely, and provides a prosthesis-tissue interface in acrylic.[39, 40] Both of these methods have their advantages and disadvantages. The metal-tissue contact provides increased rigidity and a surface that is more biologically compatible, barring that the metal is properly finished and polished prior to insertion. The disadvantage to this technique is that the contour and intaglio surface cannot be modified to increase volume if further ridge remodeling occurs. This could result in a large gap between the residual ridge and the prosthesis over time. For the wrap-around design, acrylic resin can be added to the existing acrylic to compensate for ridge remodeling. The disadvantage is that the acrylic resin will undergo degradation after a period of time. This results in a porous surface that accumulates plaque and calculus and is no longer biocompatible with the tissue. Also, the metal framework is more prone to fracture due to the decreased volume of metal used for fabrication.[40]

In order to overcome some of these prosthesis design limitations, different approaches have been adopted. Frameworks can also be fabricated utilizing an alloy that allows porcelain layering for a porcelain fused to metal (PFM) prosthesis. The framework is fabricated in one piece, and upon fitting procedures, it can be sectioned and soldered until passive fit is achieved. Some advantages of this type of restoration include high esthetics due to the porcelain layering technique. The ceramic also provides higher resistance to wear compared to resin denture teeth utilized for the hybrid prosthesis. Some disadvantages of this prosthesis include high financial burden (due to the nature of the alloys utilized and the laboratory procedures) and porcelain fracture, which is difficult to repair.[39]

A modification of this technique is the use of a titanium framework, fabricated by CAD/CAM procedures, with individual crowns cemented on. The framework is prepared to receive either PFM or lithium disilicate individual crowns. The preparations are conducted following traditional principles of tooth preparation for crowns and bridges. The buccal aspect of the framework is layered with an acrylic or composite resin to simulate the missing gingival tissue.[39] The advantage of this technique is the ease of repair compared to the PFM option because if porcelain chipping or fracture occurs, a single crown can be replaced instead of replacing the entire arch.[41] A disadvantage is the elevated cost involved with fabrication of individual crowns and a separate CAD/CAM framework. Also, the resin used to replicate the gingiva will degrade over a relatively short period of time compared to porcelain and will need to be replaced periodically.[41, 42]

Another material that was introduced to dentistry for manufacturing of prostheses is Zirconium oxide (ZrO_2), also known as zirconia. This high strength ceramic is highly biocompatible, presents low plaque surface adhesion, high flexural strength, absence of mucosal discoloration, and good esthetic properties.[38, 43, 44] Zirconia was first utilized for the fabrication of crown and bridge copings and frameworks. Zirconia restorations are fabricated using CAD/CAM procedures. A pattern is designed on the computer and then milled in a pre-sintered state since sintering results in increased hardness and brittleness. The milled structure is approximately 25% larger in size than the final product. The restoration is then sintered resulting in shrinkage to the correct dimensions.[45] Porcelain is then layered on top of this coping or framework utilizing a process similar to PFM.[46]

A disadvantage of the zirconia technique is porcelain chipping and delamination, which is shown to occur more frequently than in PFM restorations.[47-49] Modifications to

the laboratory process, such as variations in cooling rates during porcelain firing, have been proposed to decrease the risk for porcelain delamination.[50]

Some manufacturers infiltrate the zirconium oxide with aluminum oxide, which improves the optical properties. This provides a degree of translucency to the material without detrimental effects to the mechanical properties.[45] These modifications allow for fabrication of monolithic FIFPs, where the full contour of the teeth are milled into the prosthesis. Other designs entail milling of only the framework, which is followed by further porcelain layering. The zirconia prosthesis is stained before sintering in order to provide internal characterization that mimics the esthetics of the natural dentition and surrounding gingiva. External staining and minimal porcelain layering can also be applied on non-functional surfaces to improve esthetics with a minimal risk of porcelain delamination.[38]

Recent literature supports the use of monolithic zirconia full arch implant restorations for the rehabilitation of edentulous patients due to the advantages that this technology can provide. Some advantages include passive fit, ease of fabrication, highly smooth surface, similar wear to natural dentition, and less post-delivery complications.[42, 49, 51-58]

The All-on-4 treatment concept

An important factor to consider when designing the framework for a hybrid prosthesis is the cantilever length of the distal extensions. English recommended a maximum cantilever length of 1.5 times the antero-posterior spread (A/P spread) of the implants, and shorter in poor bone quality.[59]

The A/P spread of the implants is related to the position in which they were placed. Implant position is limited by important anatomical structures such as the nasal cavity and maxillary sinuses in the maxilla and the mental foramina and anterior loops of the inferior alveolar canal in the mandible.[60]

To overcome the lack of adequate A/P spread, different techniques have been described to prevent damage to the anatomical structures while still providing a more posterior placement of the distal implants. These techniques include lateralization of the inferior alveolar nerve,[61, 62] grafting of the maxillary sinus floor,[63, 64] and guided bone regeneration (GBR).[65] The latter two procedures involve a preliminary surgical intervention and a period of integration and maturation of the bone graft before implants can be placed.

Malo *et al* introduced the All-on-4 concept, which allows for the placement of four longer implants without preliminary grafting and with minimal distal cantilevers for both arches.[66] Malo proposed the placement of two anterior vertical implants and two posterior tilted implants. In the mandible, the two posterior tilted implants were placed just anterior to the mental foramina and angled distally about 30º relative to the occlusal plane. In the maxilla, the same concept was followed with the distal implants tilted to parallel the anterior sinus wall and provide the same 30º angulation.[66, 67]

Angulated transmucosal abutments, with an angle of either 17º or 30º were delivered for each implant, which allowed for angle correction and screw-access holes in the occlusal or lingual surfaces of the prosthetic teeth.[40, 66, 67] After implant placement, immediate temporary prostheses were delivered to provide immediate function when the

implants achieved 40 Ncm of insertion torque.[68] After six months of healing, implants were provided with a final restoration that had a casted or milled metal framework.[66]

Several reports on the long-term success of the All-on-4 treatment concept claim an implant success rate from 94.8% to 96.4% and a prosthesis survival rate of 99.2% to 100%, with up to ten years of follow-up.[69-73]

The concept of tilting implants to avoid bone grafting procedures for the fabrication of fixed partial dentures was previously reported by Aparicio *et al*. The authors observed a 95.2% success rate at the 5-year follow up for tilted implants.[74]

The various treatment concepts that have been compiled into the All-on-4 protocol have been previously described (tilted implant placement for graftless approach,[74] immediate implant placement,[75] and immediate loading[76, 77]). However, all of these novel concepts were used in conjunction for the first time to provide an integrated surgical and restorative solution for the edentulous patient. This solution avoids additional surgeries, thereby minimizing the patient's time, surgical morbidity, and costs that were typically associated with previous approaches.

A variety of complications have been reported in the treatment of edentulous patients with hybrid dentures. In addition to the findings reported by Zarb and Schmitt,[32] Goodacre *et al* reviewed the literature to find the most common clinical complications in implant restorations.[78] These complications were categorized based on implant loss (type of prosthesis, time of implant loss), surgical complications, marginal bone loss, peri-implant soft tissue complications and mechanical complications.

Biological complications

Goodacre *et al* reported on implant failure rates for multiple prosthetic designs. For implant-supported fixed complete dentures, there was a 9.8% failure rate in the maxilla and a 2.7% failure rate in the mandible. The authors found a higher rate of implant loss for removable implant-retained overdentures: 21.3% for the maxilla and 5% for the mandible. 3.1% of the implants were lost pre-prosthetically and 2.9% were lost post-prosthetically.[78, 79]

It was hypothesized that pre-prosthetic failures could be caused by overheating of the bone during osteotomy, infection, patient's health status, or micromotion during the healing phase. Post-prosthetic causes for implant failure include poor oral hygiene, unfavorable load, and framework misfit.[78]

Surgical complications included neurosensory disturbance, mandibular fracture, life-threatening hemorrhage, and hematoma. Marginal bone loss was observed for the majority of patients, with a bone loss of 0.5 to 1 mm during the first year and stable bone levels thereafter. Zarb and Schmitt stated that vertical bone loss should be less than 0.2 mm per year after the first year of clinical service.[32, 78]

Implants are occasionally afflicted with peri-implant diseases, namely, peri-implant mucositis and peri-implantitis. Peri-implant mucositis is a reversible inflammatory reaction of the soft tissues surrounding an implant in function.[80] Peri-implant soft tissue complications have included dehiscence, fistula formation, and gingival inflammation/proliferation.[78, 81]

Peri-implantitis was defined at the 1st European Workshop on Periodontology as an inflammatory process affecting the tissues around an osseointegrated implant in

function, resulting in loss of supporting bone.[80] Sanz & Chapple further defined peri-implantitis as the presence of bone loss ≥ 2 mm, positive bleeding on probing (BOP), probing depth (PD) ≥ 5 mm, and/or concomitant probing deepening compared to the measurements taken at the time of prosthetic placement.[82]

In a systematic review, Rakic *et al* concluded that peri-implantitis affects about 18.5% of patients and 12.8% of implants. They also found that implants with a moderately rough surface seem to be associated with a lower prevalence of peri-implantitis.[83] Gurgel *et al* reported in a cross-sectional study that peri-implant diseases affected 54% of their patients. 28% of the patients displayed peri-implantitis and 54% displayed peri-implant mucositis. The authors found that peri-implant disease was associated with a gingival index of greater than 10%, having more than two implants, and the use of medication.[84]

Cavalli *et al* found the prevalence of peri-implant mucositis to be 7.14% at the patient level, and 5.06% at the implant level. Peri-implantitis had a prevalence of 4.55% at the patient level and 3.81% at the implant level. The patients in the study group had at least one arch restored using the All-on-4 protocol and were followed for up to 130 months.[85]

Prosthetic complications

Mechanical complications of hybrid prostheses include screw loosening, screw fractures, implant fractures, framework/resin/veneering material fractures, tooth wear, implant prosthesis fractures, opposing prosthesis fractures, and metal framework fractures.[32, 78, 81, 86, 87]

Metal framework fracture has been attributed to inadequate metal thickness, poor solder joints, excessive cantilever length, poor selection of dental alloys, parafunctional habits, and improper framework design.[78, 81, 88-90]

The most common complications observed in hybrid prostheses involve the interface between the prosthetic teeth, acrylic resin, and metal framework. These complications include acrylic resin and tooth wear, prosthetic teeth debonding and fracture, and delamination of the veneering material.[78, 81, 88, 89]

Phonetic and esthetic complications are encountered more frequently in the maxilla than in the mandible. Patients with excessive resorption in the anterior maxilla and improper prosthesis-tissue contact can display air escape during speech and function. Most patients fully adapt to the shape and position of the prosthesis without speech impediments in a period of three to six months after prosthesis delivery.[78, 91]

Parel and Phillips[92] examined records of patients that received four implants for rehabilitation of 285 maxillae and 273 mandibles (2,132 implants total) and reported an implant survival rate of 96.53% for maxillae and 99.3% for mandibles. They found that primary risk factors contributing to implant failure were opposing natural dentition, poor bone density, male gender, bruxism, and implant location in a distally inclined site. The authors concluded that an extensive diagnostic assessment should be done and if risk factors are encountered, modifications should be considered to improve chances for an optimal outcome.

Ventura *et al*[87] followed 161 hybrid prostheses for a mean period of 39.69 months and observed that prosthetic tooth fracture was the main mechanical complication, which occurred in 40.4% of the prostheses. Furthermore, over 60% of these prostheses

presented with tooth fracture more than once. The maxilla had a higher number of fractures compared to the mandible. Other significant risk factors for prosthetic tooth fracture were male gender, opposing natural dentition, and prosthetic structures that lacked mechanical retention.

Complications found with the FIFP-Zr design include minor porcelain chipping (when non-functional porcelain layering is done), tooth delamination of the opposing denture (fixed or removable), abutment debonding, and prosthetic fracture.[45, 49, 51-54, 58, 93]

Bacterial plaque

Bacterial plaque has been defined as "the non-mineralized microbial accumulation that adheres tenaciously to tooth surfaces, restorations, and prosthetic appliances, shows structural organization with predominance of filamentous forms, is composed of an organic matrix derived from salivary glycoproteins and extracellular microbial products, and cannot be removed by rinsing or water spray."[94] This definition does not reflect the dynamic nature of bacterial plaque. Listgarten *et al*[95] studied plaque formation in a light microscopy study and observed that within minutes after cleaning the tooth surface, a pellicle composed of salivary proteins formed, coating teeth and other surfaces. The first bacteria to colonize the surface are predominately Gram-positive, facultative cocci and coccobacilli, which are characterized by a transient, reversible attachment to the tooth. Over time, the attachment becomes stronger through proteoglycans covering the cell wall and proteins in fimbriae and pili. The undisturbed plaque will continue to grow in thickness through cell division of adherent bacteria. On day one, the surface is covered by colonies of dividing bacteria spreading laterally, followed by proliferating bacterial growth in the

form of columns away from the tooth. By day three, species of coccoid bacteria aggregate with some of the filamentous bacteria and produce “corncob formations.” This growth pattern continues for up to three weeks until the filamentous bacteria become more prevalent. This is the typical and relatively stable structure of mature, supragingival plaque. This growth can then migrate subgingivally and modify the condition of the healthy gingival sulcus. The resultant inflammatory changes will deepen the gingival sulcus and provide an ideal environment for the proliferation of anaerobic bacteria, such as motile rods and spirochetes.[94, 95] The bacteria at the bottom of the sulcus can injure the junctional epithelium, resulting in enlarged intercellular spaces and altered integrity of the junctional epithelium’s barrier function. This allows for bacterial colonization of the root surface and deepening of the sulcus or pocket, leading to inflammatory changes that are observed in periodontal disease.[94, 96]

Socransky *et al*[97] analyzed the relationship between microbial complexes in subgingival plaque of patients with periodontal disease compared to patients with a healthy periodontium. The observed bacterial species were categorized into five major complexes based on their similarities, which were color-coded as red, orange, purple, green, and yellow. The authors observed that species in the orange complex (*F. nucleatum* subspecies, *P. intermedia, P. nigrescens*, *Peptostreptococcus micros*, *C. rectus*, *C. showae*, *C. gracilis*, *E. nodatum,* and *S. constellatus*) preceded colonization by species of the red complex (*P. gingivalis*, *B. forsythus* and *T. denticola*). These orange and red complexes exhibited a very strong relationship with pocket depth. Furthermore, sites harboring *P. gingivalis* exhibited the deepest mean pocket depths. Haffajee *et al*[98] analyzed, in a similar manner, the microbial complexes in supragingival plaque. It was

observed that supragingival microbial complexes were similar to those found in subgingival plaque samples with only a few minor differences.

Studies comparing the formation of subgingival plaque around teeth and implants have described similar methods of plaque formation and maturation.[99] In a study by Quirynen and Listgarten, bacterial morphotypes found in plaque around teeth and dental implants in partially edentulous patients were similarly distributed.[100] They also observed that in fully edentulous patients that were restored with dental implants, the plaque composition was different than that of the partially edentulous patients. The fully edentulous patients had more coccoid cells and significantly fewer motile rods and spirochetes around implants. These findings were corroborated by Mombelli *et al*[101] in a study on edentulous patients restored with dental implants. The authors found the bacteria to be made up of 85% coccoid cells and spirochetes were never detected. These bacterial populations remained stable for a two-year observation period.[99, 102] It has been established that the bacterial populations observed in healthy peri-implant tissues are similar to those observed in gingival health. Similarly, bacteria observed in peri-implant mucositis are similar to those found in gingivitis, and the bacteria found in peri-implant infection sites are almost identical to those found in periodontitis sites.[99, 103, 104]

Mombelli *et al*[105] described the microflora around peri-implantitis sites and found that in most cases the composition was similar to the microflora found in chronic periodontitis. These sites were dominated by Gram-negative bacteria, however, in some cases, peri-implant infections may include peptostreptococci or staphylococci.[104] It was also emphasized that mechanical and chemical interventions to disrupt the peri-implant biofilm have a beneficial effect on the overall implant health.[105]

Surface roughness is an important factor for plaque adhesion. The amount of deposits on different substrates is related to the degree of their surface roughness.[106] Bollen *et al*[107] reviewed the literature on surface roughness and finishing methods of different dental materials and the relationship of these variables to plaque accumulation. They reported that an increase in surface roughness above the threshold of 2 μm resulted in a dramatic increase in bacterial colonization.[108] In a separate review, Quirynen *et al*[109] considered surface roughness and surface-free energy as factors that could induce plaque accumulation. They concluded that rough surfaces will promote plaque formation and maturation and that high-energy surfaces collect more plaque, increase the strength of the bacterial bond, and have an affinity for specific bacteria. Both of these variables interact with each other, but surface roughness is significantly more critical to induce plaque adhesion.

Titanium used for the fabrication of abutments and frameworks for implant restorations undergoes a series of laboratory steps. One of the last steps in the fabrication process is the polishing and finishing of the surface. A smooth surface should be achieved to prevent plaque accumulation and facilitate hygiene procedures.[108, 110]

Kanao *et al*[111] conducted a study to compare plaque accumulation and blood flow in patients rehabilitated with FIFPs designed to have the soft tissue in contact with either titanium, acrylic, or composite resin. They found that a titanium framework presented better hygiene, less plaque adhesion, and less tissue inflammation when compared to acrylic and composite resin.

In a separate *in vivo* experiment, Scarano[112] used discs fabricated with different materials and fixed them in volunteers mouths for 24 hours. He found that bacterial

adhesion was significantly less on a zirconia surface when compared to titanium. Peri-implant soft tissues around zirconia and titanium abutments were evaluated for health and bacterial colonization by van Brakel *et al.*[113] They found shallower probing depths around zirconia abutments with no difference in the other clinical parameters and no difference in the type of bacterial colonization.

Furthermore, an *in vivo* experiment by Bremer[114] observed relative bacterial adhesion to five different dental ceramics and they found that zirconia had less plaque adhesion compared to the other four ceramics.[115]

Due to these favorable observations regarding zirconia as a hygienic choice for dental prostheses, it would be beneficial to further investigate its properties compared to traditional titanium prostheses in a clinical setting. The purpose of the present study is to compare plaque accumulation and soft tissue changes on full-arch implant-supported fixed maxillary prostheses fabricated using either a titanium framework or monolithic zirconia.

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et al[113] for health and bacterial colonization. No difference was observed in clinical parameters of the soft tissues around either material, except for shallower probing depths around zirconia abutments. No difference in the type of bacterial colonization was observed either.

Furthermore, a different *in vivo* experiment by Bremer[114] observed relative bacterial adhesion to five different dental ceramics and they found that zirconia had less plaque adhesion compared to the other four ceramics.[115]

Due to these favorable observations regarding zirconia as a hygienic choice for dental prostheses, it would be beneficial to further investigate its properties compared to traditional titanium prostheses in a clinical setting. The purpose of the present study is to compare plaque accumulation and soft tissue changes on full-arch implant-supported fixed maxillary prostheses fabricated with either a titanium framework or monolithic zirconia.

2. MATERIALS AND METHODS

Patient enrollment

The protocol for this prospective, longitudinal descriptive clinical study was reviewed and approved by the Institutional Review Board of Texas A&M University College of Dentistry (TAMUCOD), Dallas, Texas. A total of 50 patients of record at TAMUCOD were invited to participate in the study utilizing convenience sampling from the pool of maintenance patients at the Center for Maxillofacial Prosthodontics (CMP), TAMCOD. These patients had maxillary complete edentulism and have been rehabilitated in the CMP Clinic with at least four dental implants and a FIFP fabricated with either a titanium framework and resin prosthetic teeth (FIFP-Ti) or monolithic zirconia (FIFP-Zr). These prostheses must have been in function for at least six months, the patients should be enrolled in the maintenance phase of therapy, and their last maintenance appointment had to be at least three months before enrollment. Inclusion criteria: 1) At least 18 years of age, 2) Must have received a maxillary FIFP-Ti or FIFP-Zr, supported by at least four dental implants, 3) Must have a patient chart with radiographs at the TAMUCOD clinical system. Exclusion criteria: 1) Uncontrolled or poorly controlled systemic conditions (ASA III or greater) that might contraindicate routine dental prophylaxis, 2) Patients who have taken antibiotics in the last three months, 3) Patients who are prisoners or are incarcerated before or during enrollment.

22 patients attended the initial screening appointment and two patients were rejected due to the selection criteria. One patient had a FIFP-Ti that was fabricated with the wrap around design and did not have titanium in contact with the soft tissue. The

second patient displayed implant failure of four of the six maxillary implants and was referred to the Graduate Oral and Maxillofacial Surgery Clinic for implant removal and maxillary reconstruction.

Clinical protocol

Patients were scheduled for three clinical appointments to have routine maintenance procedures for their maxillary FIFPs and their mandibular arches as needed. When the mandibular arch had natural dentition, the maintenance procedures were completed by a Registered Dental Hygienist at the CMP Clinic. If the patient had a mandibular FIFP, the normal FIFP maintenance protocols were completed. Three separate maintenance appointments scheduled at three month intervals were designated as time zero (T0), time one (T1), and time two (T2). This resulted in a six-month observation period for each patient.

The first appointment (T0) lasted approximately 90 minutes and consisted of explanation of the study protocol, answering patients' questions, obtaining informed consent, and rendering of clinical procedures according to protocol. During visits two and three (T1 and T2), only the clinical procedures were completed.

Clinical procedures for all appointments were identical and included removal of the prosthesis, data collection (described in detail below), extraoral cleaning of the prosthesis in the laboratory, and redelivery of the prosthesis after hygiene.

After removing the FIFPs from the mouth, they were cleaned in the dental laboratory until they were free of plaque and calculus utilizing the following methods. Bacterial plaque was wiped off with wet gauze and the prostheses were steam cleaned.

When calculus was observed, prostheses were submerged in an ultrasonic bath filled with calculus and stain remover solution (Patterson Dental) and subjected to ultrasonic vibration for 20 minutes. This was followed by a second ultrasonic bath in distilled water for 2 minutes and steam cleaning. If the prostheses presented surface alterations or surface roughness during the first appointment, polishing was carried out following standard laboratory procedures.

Data collection

Data collection was organized into 3 different data sets:

1) Plaque Area Index (PAI)[111] was measured by photographic analysis. After removal of the prosthesis, plaque was stained using dental disclosing solution (2 Tone, Young Dental), rinsed under running water, and photographed using a standardized method. A D-SLR camera (D3300, Nikon) with a macro lens (Micro 85mm f3.5, Nikkor) and a ring flash (Mecablitz 15 MS-1, Metz) with pre-configured settings was used for all photographs (see Figure 1). The camera was attached to an assembly[116] to maintain the same distance and angulation between the camera lens and the stained intaglio surface of the prosthesis.

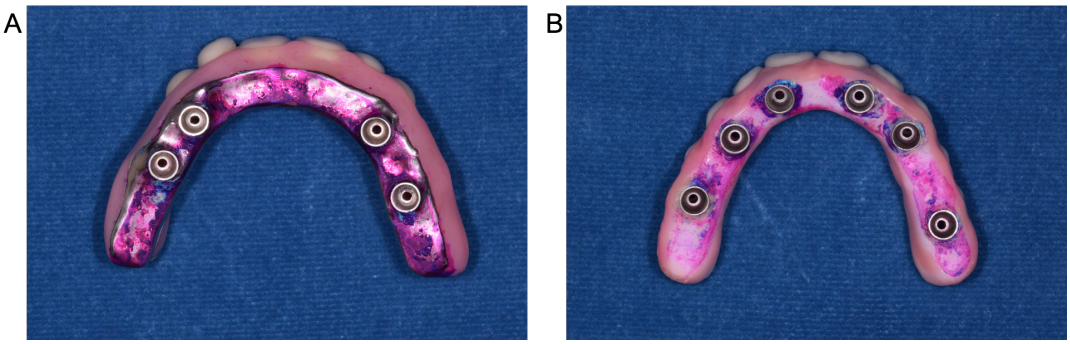

Figure 1. Prostheses stained with disclosing solution. A) FIFP-Titanium. B) FIFP-Zirconia.

2) Implant parameters were assessed as proposed by Mombelli *et al*[117], de Araujo *et al,*[118] and Wennstrom *et al,*[119] using two blinded, calibrated, board-certified periodontists (Dr. Jeffrey Rossmann and Dr. Garth Griffiths):

- **Modified Plaque index (mPI):** A calibrated 12-UNC plastic probe (Hu-Friedy) was introduced 1 mm into the implant sulcus and moved circumferentially around the implant or abutment to assess plaque accumulation using a modified plaque index (mPI). This was recorded dichotomously as present or absent.
- **Modified Bleeding Index (mBI):** Bleeding tendency was evaluated during measurement of the modified plaque index. This parameter was recorded dichotomously as well.
- **Implant mobility (MOB)** was evaluated by application of bucco-lingual force with two blunted instruments (dental mirror handles). This was also recorded dichotomously as either present or absent.
- **Implant probing depths (PD) ≥ 5mm** were evaluated in 4 sites per implant (mesial, buccal, distal and palatal) with a calibrated 12-UNC plastic probe (Hu-Friedy) and recorded as present or absent.
- **Suppuration (SUP)** was assessed by applying pressure with two fingers to the peri-implant tissue on both vestibular and palatal sides and registered as present or absent.

- **Keratinized Tissue (KT) band ≥ 2mm** was measured circumferentially around the implants with a calibrated 12-UNC plastic probe (Hu-Friedy) and recorded as present or absent.

3) Intraoral occlusal photographs of the edentulous ridge (without the prosthesis) were obtained utilizing the same D-SLR camera configuration as mentioned previously, using standardized manual settings. Columbia cheek and lip retractors (Hu-Friedy) and an occlusal titanium coated glass photographic dental mirror (Photomed) were used. The camera's angle and position were kept as similar as possible throughout appointments. Photographs included the entire upper ridge, extending posteriorly to capture the most distal dental implants.

The collected data was divided into two groups for analysis: Group Ti included data collected from patients that were restored with a FIFP-Ti and Group Zr included data collected from patients that were restored with a FIFP-Zr.

The first dataset, consisting of standardized photographs to measure PAI, was analyzed (as shown in Figure 2) utilizing ImageJ software (NIH, Bethesda, MD).[120] The intaglio area of the prosthesis was quantified in pixels and the area occupied by the circumference of the implant connectors was manually subtracted. The area stained by microbial plaque was analyzed relative to the adjusted area (intaglio area minus connectors) to calculate a percentage.[111]

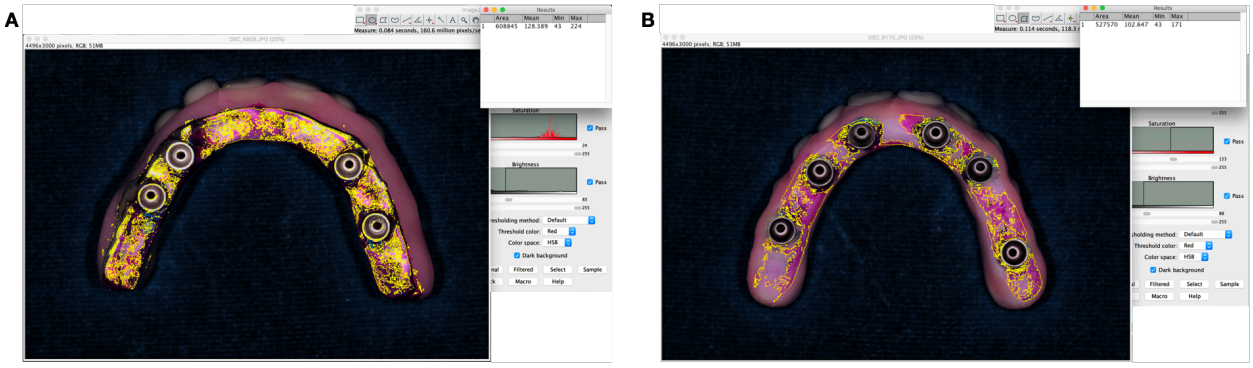

Figure 2. Photographic analysis utilizing Image-J Software. A) FIFP-Titanium. B) FIFP-Zirconia.

The third dataset, containing occlusal clinical photographs of the maxillae without prostheses, was evaluated for erythema (redness) of the tissue in contact with the prosthesis (Figure 3) by a panel of experts (Dr. Garth Griffiths, Dr. Jeffrey Rossmann, and Dr. Stephen Harrel). Photographs were subjectively evaluated according to the area that presented erythema and were given a grade of 1, 2, or 3: 1) No erythema, 2) Erythema present in ≤30% of the edentulous ridge, and 3) Erythema present in >30% of the edentulous ridge. Examiners were in an isolated room, with similar lighting and climate conditions; each image was presented for 30 seconds in a 65" HD screen.[121] Examiners were blinded to the type of FIFP (titanium or zirconia).

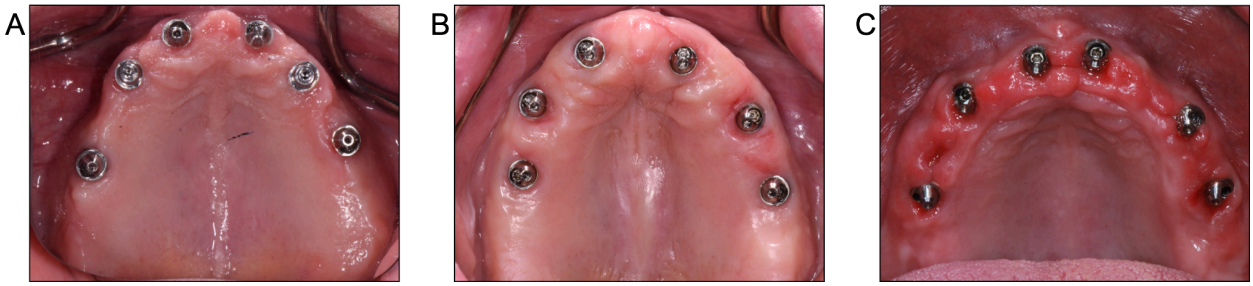

Figure 3. Erythema analysis in the soft tissue in contact with the prosthesis. A) No erythema. B) Erythema present in ≤30% of the edentulous ridge. C) Erythema present in >30% of the edentulous ridge.

Statistical Analysis

Continuous parameters are reported as mean ± standard deviation, and discrete parameters are reported as n and percent (%). The unit of analysis for this study was the patient, with teeth nested within patients. Generalized estimating equations (GEE) for repeated measures were constructed to compare the two procedures (Titanium versus Monolithic Zirconia) on changes over time in the mPI (Modified Plaque Index), sulcus bleeding (mBI), implant pocket, mobility, suppuration, and keratinized tissue band. The fixed-effects portion of each model was procedure and the random effects portion of each model was the patient and implant. Time was specified as the repeated effect, with 3 levels (Baseline, 3-month, and 6-month), based on binomial distributions. Plaque area was analyzed with mixed factorial MANOVA with procedure as the between-subjects variable and time as the within-subjects variable. Erythema ratings by the three evaluators were analyzed with a doubly multivariate mixed factorial MANOVA. Spearman rank-order correlation coefficients were computed to identify associations between plaque area and erythema. The study alpha was set to .05. Analyses were performed with SPSS 23.0 (IBM, 2017).

3. RESULTS

20 patients were enrolled in the study (11 women and 9 men; age range: 24 to 82, mean age: 64 years), consisting of 7 patients in group Ti and 13 patients in group Zr. One patient from group Zr dropped out and did not attend the third appointment, therefore, a total of 19 patients completed the study.

Implant parameters

Mobility (MOB) could not be analyzed because all implants received a value of zero (absent) for all time points.

Suppuration (SUP) could not be analyzed because most implants received a value of zero (absent) for most time points.

The GEE model for the mPI indicated that there was no significant effect for procedure, Wald $\chi^2(1) = .002$, $p = .97$. However, both groups trended toward increases in plaque over time, $\chi^2(2) = 5.41$, $p = .067$). There was no significant interaction between procedure and time for the mPI, $\chi^2(2) = 2.92$, $p = .24$).

The GEE model for sulcus bleeding (mBI) indicated that there was no significant effect for procedure, Wald $\chi^2(1) = .20$, $p = .65$. However, both groups exhibited significant increases in sulcus bleeding over time, Wald $\chi^2(2) = 59.39$, $p < .001$). There was no significant interaction between procedure and time for sulcus bleeding, Wald $\chi^2(2) = 4.12$, $p = .13$).

The GEE model for probing depths (PD) indicated that there was no significant effect for procedure, Wald $\chi^2(1) = 1.20$, $p = .27$. However, both groups trended toward

increases in PD over time, Wald $\chi^2(2) = 5.41$, $p = .067$). There was no significant interaction between procedure and time for PD, Wald $\chi^2(2) = .43$, $p = .81$).

The GEE model for keratinized tissue band (KT) indicated that there was a significant effect for procedure, Wald $\chi^2(1) = 5.51$, $p = .019$. The implants in the FIFP-Ti group had significantly higher levels of keratinized tissue band than the implants in the FIFP-Zr. There was no significant effect for time, Wald $\chi^2(2) = .44$, $p=.81$), indicating that keratinized tissue band levels remained constant over time for both groups. There was no significant interaction between procedure and time for sulcus bleeding, Wald $\chi^2(2) = 1.12$, $p = .57$).

Plaque area index

The mixed factorial ANOVA for plaque area (PAI) indicated a marginal effect for procedure, $F(1,17) = 3.96$, $p = .06$. On average, the FIFP-Zr had lower plaque area levels than the FIFP-Ti. There was no significant effect for time, $F(2,16) = 1.37$, $p=.28$. However, there was a significant interaction between procedure and time for sulcus bleeding, $F(2,16) = 3.65$, $p = .049$). As shown in Figure 4, the pattern of change over time was significantly different between the two groups. The plaque area of the Zr group significantly decreased over time, $F(2,10) = 4.80$, $p=.035$, whereas the plaque area of the Ti group remained constant over time, $F(2,5) = .94$, $p=.45$.

Erythema

Nonparametric correlations between plaque area and erythema indicated significant associations at baseline ($r_s = .58$, $p=.008$), 3-month follow-up ($r_s = .44$, $p=.05$),

and 6-month follow-up (r_s = .52, p=.024). Higher percentages of plaque area were correlated with increased levels of erythema. The mixed factorial MANOVA for erythema indicated no significant effect for procedure, F(1,17) = .07, p = .80, and no significant interaction F(3,33) = 1.91, p = .15. There was a significant effect for time, F(3,33) = 3.11, p = .04, indicating that both groups' erythema levels significantly decreased over time (see Figure 5). Descriptive statistics are summarized in Table 1.

	Baseline		**3 Month**		**6 Month**	
	Titanium	**Zirconia**	**Titanium**	**Zirconia**	**Titanium**	**Zirconia**
Modified Plaque Index (MPI) n (%)	4 (10.3%)	4 (5.4%)	4 (10.3%)	9 (12.2%)	5 (12.8%)	14 (20.6%)
Modified Sulcus Bleeding Index (MBI)	28 (71.8%)	40 (54.1%)	26 (66.7%)	30 (40.5%)	25 (64.1%)	45 (66.2%)
Implant Pocket	6 (15.4%)	7 (9.5%)	8 (20.5%)	9 (12.2%)	9 (23.1%)	12 (17.6%)
Suppuration	0 (0%)	0 (0%)	0 (0%)	3 (4.1%)	2 (5.1%)	6 (8.8%)
Keratinized Tissue Band	26 (66.7%)	36 (48.6%)	27 (69.2%)	37 (50%)	28 (71.8%)	33 (48.5%)
Plaque Area, $\bar{X}$(SD)	48.6 (16.1)	40 (16.1)	54.5 (18.9)	40.5 (16.9)	55.6 (16.6)	34.3 (14.3)
Erythema, Median, $\bar{X}$(SD)	1, 1.4 (.7)	1, 1.0 (.6)	1, .9 (.8)	1, .9 (.7)	1, 1.1 (.7)	1, 1.0 (.9)

Table 1. Descriptive Statistics for Study Variables.

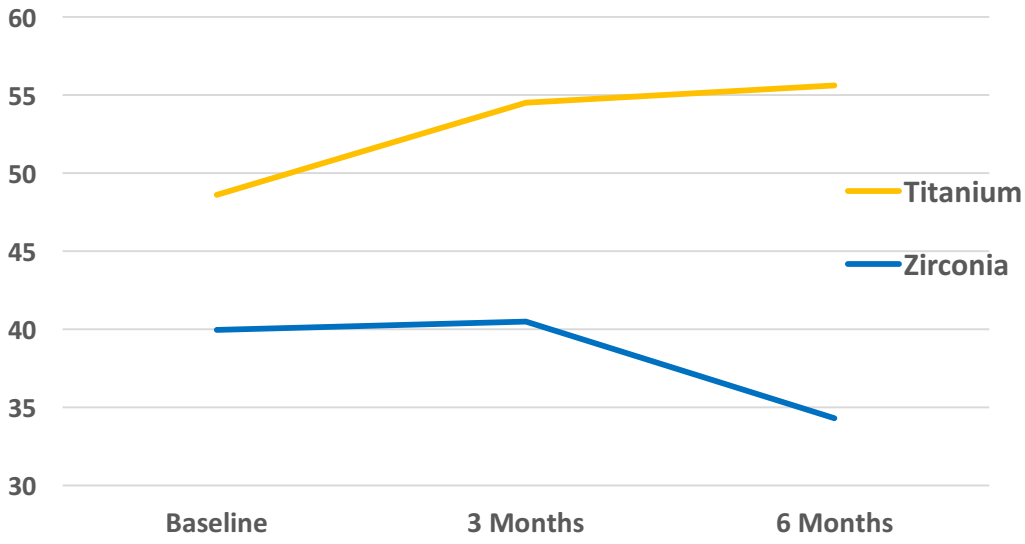

Figure 4. Plaque Area Index pattern of change over time.

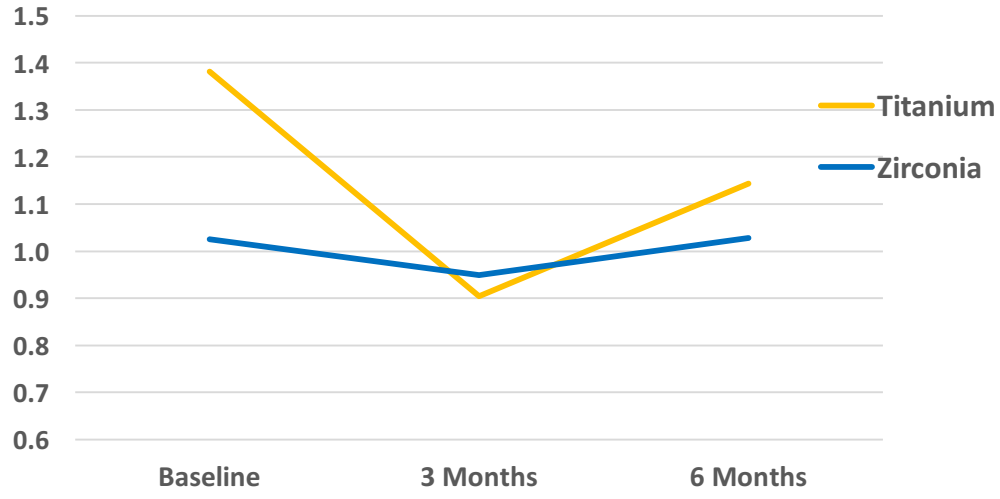

Figure 5. Erythema levels over time.

4. DISCUSSION

To the author's knowledge, this is the first report that compares the relative plaque accumulation on FIFP-Ti versus FIFP-Zr *in vivo*.

An increase in the prevalence of edentulism and access to health care involving dental implants will result in a greater number of patients seeking maintenance of these complex dental appliances.[6, 7]

Maintenance protocols for FIFPs are proven to be essential to prevent excessive plaque accumulation and the resultant immunologic response. By studying a pool of patients that had FIFPs restored in the same clinic, similar clinical and laboratory procedures were completed for these patients. All FIFPs in this study were fabricated using the same materials and a similar design. The first appointment was utilized as a baseline time point in order to further standardize and control for any unknown factors contributing to plaque accumulation. All FIFPs were inspected and cleaned and oral hygiene instructions were given to all patients. When necessary, laboratory procedures were carried out to remove any surface roughness on the FIFPs.

Similar homecare instructions were provided for each patient at T0 and reinforced at T1 and T2. The use of specific hygiene devices was emphasized, including water flossers, super-floss®, and implant care brushes (Tepe®).[122]

Two frameworks in the Ti group showed heavy calculus accumulation upon removal from the mouth at T0. Scratches were noted on the intaglio titanium surface, presumably from the use of ultrasonic scalers or other abrasive instruments during previous hygiene procedures. Hallmon *et al*[123] and Rapley *et al*[124] reported that sonic

scalers and metallic curettes drastically alter the surface of titanium implant abutments. Therefore, the use of these instruments should be avoided during implant maintenance appointments.

No calculus or surface roughness was observed for any of the FIFPs in the Zr group at any time point.

Dental plaque was cleaned from the prostheses with wet gauze followed by steam cleaning. At this point, FIFPs in the Zr group were free of plaque and debris and no further steps were needed. Most FIFPs in the Ti group had mild calculus in localized sites, which warranted further cleaning. These Ti prostheses were subjected to further cleaning in an ultrasonic bath. Average extraoral cleaning time was 2 minutes for FIFP-Zr and 24 minutes for FIFP-Ti. This parameter was not included in the original protocol and is just described in an anecdotal manner by the author.

The difference in necessary cleaning measures for FIFP-Ti versus FIFP-Zr was clinically significant in time and effort. This can be further translated to a more stringent homecare regimen for the FIFP-Ti patients. If patients are compliant, it might be easier and faster to achieve a plaque-free surface on the FIFP-Zr than on the FIFP-Ti. However, with non-compliant patients, a lack of proper homecare for FIFP-Ti could prove to be detrimental to the patient's oral health.

This observation of relative plaque accumulation can be further quantified using the PAI data. In the Ti group, the PAI remained constant throughout time points despite the regular cleanings and oral hygiene instructions. In the Zr group, the PAI remained constant from T0 to T1, however, it decreased from T1 to T2. Kanao *et al*[111] observed PAI on FIFPs-Ti of 68.1% at baseline and 59.3% at 3 months. The PAI in the Ti group for the

present study had a slight increase over time (T0=48.6%, T1= 54.5% and T2=55.6%). A major difference between the Kanao study and the present study is that Kanao *et al* included maxillary and mandibular prostheses, while the present study only included maxillary prostheses. In the author's clinical observations, maxillary and mandibular FIFPs display different patterns of plaque accumulation due to differences in design and patient anatomical factors.

Since OHI was reinforced at each appointment for all patients, it is hypothesized that all patients were able to engage in homecare procedures that they were not following prior to being enrolled in the study. However, patients in the Zr group were able to effectively decrease their plaque accumulation because the material is easier to clean.

5. CONCLUSIONS

At the initiation of this study, full-arch implant-supported fixed prostheses (FIFPs) that were fabricated from zirconia displayed slightly less plaque accumulation than those fabricated from titanium. Zirconia FIFPs displayed a significant decrease in plaque accumulation after performing periodic maintenance procedures and oral hygiene instructions. However, Ti FIFPs had significantly higher plaque levels than Zr at all time points and did not respond to maintenance and oral hygiene measures. A custom maintenance protocol should be developed for each patient, including proper removal and cleaning of the prosthesis as well as proper oral hygiene instructions. The present study suggests that zirconia responds well to plaque control measures, while plaque control on titanium may prove to be quite difficult.

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