Hybrid implant-supported restorations bonded to nitride-coated titanium bases: a clinical method to address biologic, functional, and esthetic challenges in the esthetic zone

Rafael del Castillo, DDS/Carlo Ercoli, DDS, CDT, MBA/Rafael Valera, CDT/
José María Díaz Fernández, MD, PhD/Miguel Padial-Molina, DDS, PhD/Javier Ata-Ali, DDS, MS, MPH, PhD

Objective: To describe how advancements in digital technologies and materials science provide additional restorative alternatives and material combinations for single- and multiple-unit implant-supported restorations, such as those incorporating the clinical use of nitride-coated titanium bases in combination with the two-piece, CAD/CAM, screw-retained, zirconia-ceramic, hybrid implant-supported restoration concept. **Case presentation:** Two partially edentulous patients with missing teeth in the maxillary esthetic zone were treated with a novel technical and restorative concept using the two-piece CAD/CAM screw-retained zirconia-ceramic hybrid-abutment crown concept bonded to nitride-coated titanium bases. Biologic outcomes showed that tissues were maintained healthy with the patients showing an adequate oral hygiene level, no detectable plaque present upon probing, and no bleeding on probing. Esthetic evaluation demonstrated an excellent esthetic outcome and peri-implant soft-tissue integration with adjacent natural teeth and pontic tissue areas, together with posttreatment stability of the gingival zenith position. Neither of the two patients showed technical complications such as screw loosening or porcelain chipping/fracture. Radiographic evaluation revealed a precise fit between nitride-coated titanium bases and the implant connecting interfaces, no marginal bone loss, and stable implant osseointegration. The principal advantages of incorporating nitride-coated titanium bases in implant-supported restorations rely on the favorable esthetic outcomes, improved technical, mechanical, and biologic aspects, as well as the physicochemical characteristics of nitride-coated titanium bases' hard thin film coatings and their positive impact on titanium biocompatibility. **Conclusions:** The short-term promising clinical outcomes of the two-piece CAD/CAM screw-retained, zirconia-ceramic hybrid-abutment crown concept bonded to nitride-coated titanium bases, indicate the potential clinical benefits of the described restorative alternative. However, additional in vitro investigations and randomized clinical trials are needed to validate these initial observations, especially those evaluating the two-piece CAD/CAM screw-retained, zirconia-ceramic hybrid-abutment crown bonded to nitride-coated titanium bases when compared to the conventional two-piece hybrid design as well as stock/custom, metal/zirconia/lithium disilicate, screw/cemented implant-supported restorations.

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Single implant-supported restorations can be clinically challenging, especially in the maxillary esthetic zone. Due to its advantageous mechanical and biocompatible properties, titanium has been the preferred material for screw/cement and stock/custom implant abutment fabrication[1,2]; however, titanium abutments present esthetic limitations due to peri-implant mucosa discoloration, especially when a thin gingival phenotype is present.[3,4] To overcome these esthetic limitations, one-piece monolithic zirconia implant abutments have been recommended[5]; however, in-vitro studies indicate that the fracture resistance of one-piece monolithic zirconia implant abutments is half of that reported for titanium abutments.[6]

Similarly, to overcome the mechanical limitations of one-piece zirconia implant abutments (while maintaining a titanium-to-titanium contact), enhance the esthetic advantages of an all-ceramic restoration, and reduce the possibilities of biologic complications associated with cement-retained restorations, the two-piece, screw-retained hybrid-abutment crown concept has been recommended.[7,8] The conventional hybrid-abutment crown concept consists of two distinct designs,[9,10] in which titanium (metallic) bases are used as the connecting interphase of the restoration.

Recent studies indicate that titanium alloy can be coated with titanium nitride (TiN) hard thin film coating to couple the biomechanical properties and biocompatibility of titanium alloy with the requirements for esthetics in anterior implant cases.[11-13] Additional investigations have shown TiN coating to have high chemical inertness and a low friction coefficient,[12,14] and be capable of changing the implant/abutment's surface chemical composition of titanium alloy substrate. Moreover, this interactivity is shown to reduce the interaction with biologic fluids, decreasing bacterial adherence and biofilm formation, and therefore improving its biocompatibility.[15,16] Investigations have also demonstrated an improvement of the implant/abutment's mechanical properties when coated with TiN, and have estimated that nitride coatings can increase hardness and wear resistance of pure titanium[17-20] by approximately 10 times (TiN Vickers hardness of 1,300).[21] In this sense, investigations have determined TiN hardness to be within a range of 15 to 26 GPa.[22,23]

Nitride hard thin film coatings, when applied onto a titanium surface, produce a natural phenomenon known as "light interference," creating a yellow color film coating[24] with a 580 to 582-nm wavelength and 0.84 purity that has been found to be close to that of the pure gold reference spectrum (579 nm wavelength and 0.91 purity).[13] From the esthetic point of view, investigations have shown clinical advantages of gold color TiN-coated abutments and have found them to be advantageous for abutment peri-implant soft tissue integration, especially in anterior esthetic areas with a thin gingival phenotype (≤ 2 mm).[25-27]

Recent publications indicate how TiN coating can be used in combination with CAD/CAM abutments (Atlantis Gold Hue Abutment, Dentsply Sirona) and cemented restorations.[28-31] However, advancements in digital technologies and materials science provide additional restorative alternatives and material combinations for single- and multiple-unit implant-supported restorations, such as those incorporating the use of nitride-coated titanium bases. To date, and to the best of the present authors' knowledge, only in vitro investigations[32,33] have been published describing the outcomes of relevant laboratory investigations using TiN-coated titanium bases in combination with screw-retained restorations, and no previous scientific reports describing the clinical use of two-piece, CAD/CAM, screw-retained, zirconia-ceramic, hybrid implant-supported restorations bonded to TiN-coated titanium bases have been documented.

Therefore, with the paucity of previous reports, the purpose of the present manuscript was threefold:

- to describe the most up to date scientific evidence on TiN hard thin film coating, identifying the most relevant clinical, biologic, mechanical, and esthetic advantages when applied to restorative implant dentistry
- to describe a novel technical and restorative protocol applied to treat two partially edentulous patients with high esthetic and functional expectations and missing teeth in the maxillary esthetic zone, using the two-piece, CAD/CAM, screw-retained, zirconia-ceramic, hybrid implant-supported restorations bonded to TiN-coated titanium bases
- as a consolidated treatment approach used by the present authors for several years, outline the benefits, advantages, and disadvantages of the proposed restorative concept when compared to the "conventional" (using standard titanium bases) CAD/CAM screw-retained, two-piece hybrid-abutment crown concept.

Method and materials

Subject selection

All clinical information that is relevant to this scientific report was collected retrospectively from a single private practice. The clinical and laboratory data generated are part of a clinical routine and standard of care received by the patients when the clinical needs, as well as expected clinical outcomes of the patients, meet the indications for applying the described restorative clinical protocol.

Clinical procedures

After a routine diagnostic protocol recording the patient's chief complaint and medical and dental history, an extraoral and intraoral clinical examination was performed. A diagnosis and an individualized treatment plan was established for each patient based upon clinical findings, radiographic examination, and patient desires. Following a review of all treatment options, advantages, and limitations, the patients consented to the following treatment plans, as described in Case 1 and 2.

Fig 1a and b Case 1. *(a)* Frontal view of maxillary left central incisor. Although a healthy periodontium is observed in the maxillary anterior teeth, darkening of left central incisor's cervical third is obvious. *(b)* Radiographic analysis shows periapical radiolucency and slight apical root resorption in central incisor. Although radiolucency seems to be affecting the left lateral incisor apex, the tooth was asymptomatic.

Case presentation

Case 1

A 41-year-old woman with a noncontributory medical history, no stated food or drug allergies, and without contraindications for dental treatment, was referred for prosthodontic evaluation and treatment of her maxillary anterior teeth. The patient's chief complaint was a high dissatisfaction with her smile appearance due to darkening in the cervical third of the maxillary left central incisor, as well as pain under pressure and percussion of this tooth.

At clinical examination, the patient showed healthy periodontal tissues, highly scalloped-thick periodontal phenotype, no bleeding on probing with 3 mm probing depth all around, except in the mesial aspect of the maxillary left central incisor, which showed a 4.5-mm probing depth. Radiographic examination showed root canal treatment on both teeth performed at the age of 17 years old. The central incisor presented slight and irregular widening of the mesial aspect of the periodontal ligament (PDL) as well as periapical radiolucency and apical root resorption. Although periapical radiolucency seemed to be affecting the apex of the left lateral incisor, the tooth was asymptomatic (Fig 1).

The maxillary left central incisor was deemed unrestorable due to objective clinical and radiographic signs, which were determined to be compatible with a root fissure. Treatment plan options were established and presented to the patient. The patient elected an implant-supported single-tooth restoration on the maxillary left central incisor. No treatment was determined for the left lateral incisor. The first phase of restorative treatment included the atraumatic extraction of the maxillary left central incisor, debridement of the socket with surgical curettes

Fig 2 Case 1. In the provisional phase, the patient's high esthetic expectations were met with a zirconia ceramic cantilevered resin-bonded fixed dental prosthesis. The use of a permanent resin cement was necessary to avoid technical complications such as interim prosthesis decementation during the initial 6 months.

Fig 3 Case 1. Frontal view of screw-retained interim restoration after 6 months. Gingival tissue architecture was maintained during the provisional phase; however, due to the impossibility of rescheduling the patient during the provisional phase, tooth contour, incisal edge position, and interproximal line angles could not be improved prior to definitive restoration fabrication.

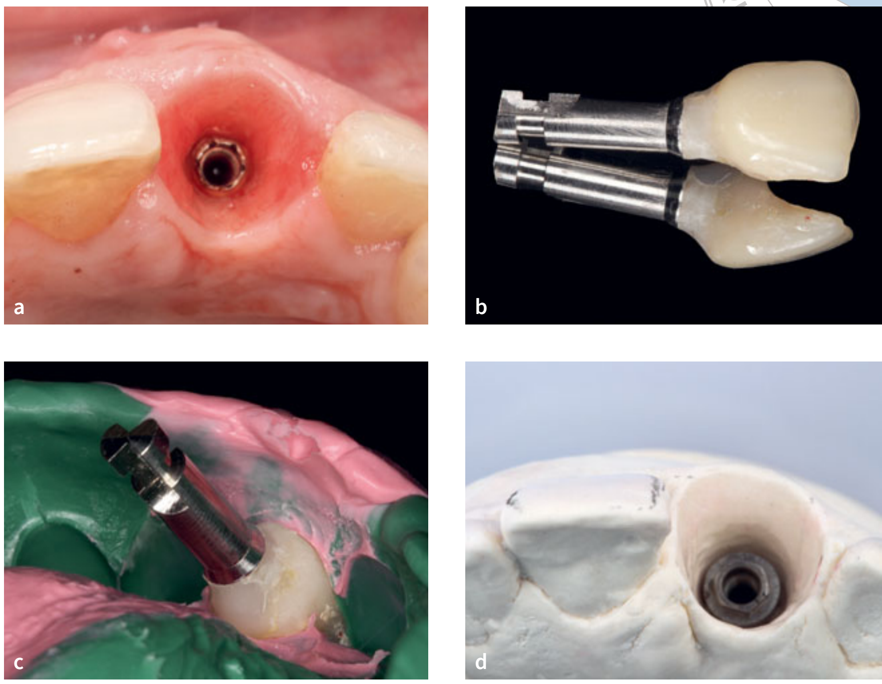

Fig 4a to d Case 1. *(a)* Occlusal view of peri-implant soft-tissue after interim restoration removal. Adequate buccal thickness of soft tissue allowed its contouring and manipulation in order to develop a proper emergence profile and peri-implant esthetic clinical outcomes. *(b)* Interim screw-retained PMMA provisional restoration connected to implant analog prior to replacement within final impression. *(c)* Placement of central incisor's provisional crown/implant analog within final impression prior to impression pouring. *(d)* Working master cast with implant analog where peri-implant soft tissue was replicated in stone for improved precision while designing final restoration.

to remove any remaining soft tissue, and the insertion of a zirconia ceramic cantilevered resin-bonded fixed dental prosthesis bonded to the maxillary right central incisor using a dual polymerization composite resin cement (Variolink Esthetic DC, Ivoclar Vivadent).[34] Care was taken to eliminate all cement residues before composite resin cement complete setting (Fig 2).

Three months were allowed for hard and soft tissue maturation, after which a transmucosal external hex implant (4 × 13 mm MKIII TiUnite Implant, Brånemark Implant System, Nobel Biocare Services) was placed together with a simultaneous buccal connective tissue graft in order to improve buccal peri-implant soft tissue thickness. Primary stability (as determined by insertion torque) was obtained during implant placement. Therefore, an immediate provisionalization protocol was used to fabricate a screw-retained interim implant-supported single-tooth restoration, using an implant level, nonrotational titanium temporary abutment.[35] Six months were allowed for implant osseointegration, after which the second phase of restorative treatment was initiated (Fig 3).

Due to the buccal implant angulation, the need for a retrievable restoration, and the high esthetic expectations, the patient elected a final restoration fabricated using an implant level, zirconia-ceramic (veneering technique), screw-retained, hybrid-abutment crown with an angulated screw channel (ASC)[36] bonded to a nitride-coated titanium base. Due to the impossibility to reschedule the patient during the provisional phase to conform the central incisor's interim restoration to ideal anatomical dimensions and emergence profile in a staged approach, the final impression was made capturing the transmucosal emergence profile and anatomical contours, as determined by the central incisor's implant-supported temporary restoration initial contours.

The implant-level final impression was made using the pick-up impression technique with a custom tray using the one-step, double mix impression technique with a vinyl-polyether silicone impression material (EXA'lence 370, GC).[37] After impression material setting, interim restoration was unscrewed, connected to an implant analog, and inserted within the impression to fabricate the working cast. This procedure allowed transference of the preliminary information to the first definitive master cast (Fig 4).

In order to consistently determine and transmit the tooth's color map to the dental technician, Vitapan 3D-Master Shade Guide System and Vita Classic Shade Guide System (Vita Zahnfabrik) were used together with digital photographs. Preliminary digital photographs with both shade guides using standard exposure technique and the cross-polarized light filter technique[38] were made to determine hue, value, chroma, translucency, opalescence, and the main body color of adjacent and opposing teeth.

Based on the central incisor's temporary restoration design and anatomical contours, the central incisor's CAD/CAM final

Fig 5a to d Case 1. In the hybrid-abutment crown concept, the titanium insert is prefabricated by the implant manufacturer or CAD/CAM provider while the ceramic mesostructure is customized by CAD/CAM technology based on the clinical restorative and esthetic needs. *(a)* 0.5-mm-high finish line nitride-coated Ti-base prior to connection to zirconia mesostructure. *(b)* Zirconia mesostructure fabricated using prefabricated zirconia blocks made of pre-sintered zirconia and having a connection geometry for attaching to the titanium insert. *(c)* During restorations design, pencil marks were made on the trial restoration and adjacent central incisor to compare location of height of contour, interproximal line angles, and cervical emergence profile. *(d)* Anatomical contours of preliminary restoration were evaluated during first bisque-bake clinical try-in.

restoration was manufactured following the conventional two-piece (Ti-base) screw-retained hybrid-abutment crown concept, with the exception that a TiN base was used instead of the conventional metallic Ti-base. The TiN titanium base (TiN-base Custom Interface System, IPD Dental Group) was provided by the CAD/CAM manufacturer and included the following features: 0.5 mm finish line height, 5.5 mm post height, and horizontal helicoidal retentive features. After final restoration design was completed by means of CAD software (Exocad), the ceramic mesostructure was milled using a pre-sintered zirconia block (IPS e-max ZirCAD, MO, Ivoclar Vivadent). Sintering and crystallization of the zirconia mesostructure was done according to the manufacturer's recommendations. After veneering the zirconia mesostructure with feldspathic porcelain (Creation, Willy Geller International), ceramic restoration was temporarily fitted to the TiN base with cyanoacrylate adhesive for initial bisque-bake try-in (Fig 5).

As part of the initial clinical bisque-bake try-in, standard exposure and cross-polarized filter digital photography was used again to verify the restoration's esthetic integration. A second bisque-bake clinical try-in to verify color, surface texture, anatomical contours, emergence profile, and peri-implant soft tissue integration and architecture was done. Final conformation of crown anatomy, including fine adjustments of line angles, surface texture, and restorative emergence profile was performed on a second master cast obtained from a transfer impression capturing the second bisque-bake trial restoration.

Prior to the restoration's final clinical insertion, the zirconia-ceramic mesostructure was bonded to the TiN base according to the following protocol:

- for the titanium base, airborne-particle abrasion with 50 µm Al_2O_3 at 2.5 bar at 10-mm distance + Monobond Plus for 60 seconds
- for the zirconia-ceramic mesostructure, Monobond Plus for 60 seconds.

Bonding procedures were completed using a thin layer of a dual-polymerizing composite resin cement (Panavia F 2.0, Kuraray) for cementation of the zirconia-ceramic mesostructure on the TiN base (Fig 6).

After restoration completion, the restoration was inserted by means of a TPA screw (TPA Screw System for Angulated Screw Channels/ASC, IPD Dental Group). The abutment screw was torqued to 25 Ncm following the manufacturer's recommendations. The screw access channel was then sealed with polytetrafluorethylene (PTFE) tape and microhybrid composite resin (Fig 7).

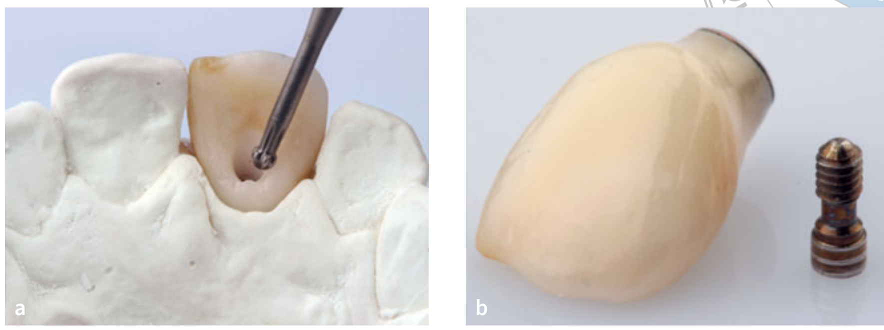

Fig 6a and b Case 1. *(a)* Palatal view of completed restoration in master cast prior to clinical insertion. A specifically designed six-lobe screwdriver is used for the screw-retained hybrid restorations with the angulated screw channel (ASC) system used in this case. *(b)* Completed restoration and TPA screw prior to clinical insertion.

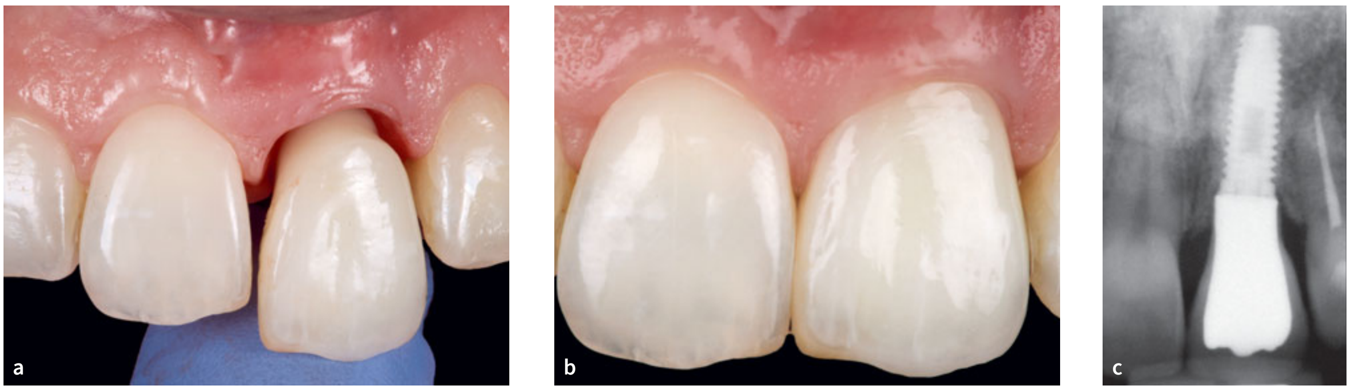

Fig 7a to c Case 1. *(a)* Clinical insertion of completed restoration. Restoration's emergence profile and interproximal location of contact points are key determinants for the final peri-implant gingival margin and interproximal papilla position. *(b)* Successful peri-implant health and esthetic integration with adjacent teeth is observed 2 months after restoration's clinical insertion. *(c)* Radiographic evaluation after 2 months of treatment completion reveals a precise fit between TiN titanium base and implant connecting surface, no marginal bone loss, and a stable implant osseointegration.

Case 2

A 59-year-old Caucasian woman was referred for prosthodontic evaluation and treatment of her maxillary anterior dentition. The patient's chief complaint was a high dissatisfaction with her smile appearance and maxillary anterior teeth esthetics. Her medical history was noncontributory and presented no contraindications for dental treatment.

Intraoral examination revealed that the maxillary right central incisor had been restored by means of a single, implant-supported, screw-retained zirconia-ceramic (veneering technique) restoration 4 years prior to clinical examination, while the maxillary right and left lateral incisors and left central incisor were restored with individual (non-splinted) zirconia ceramic tooth-supported full-coverage restorations, which had been in clinical function for the last 19 years.

Radiographic examination showed an external hex implant (13 × 4 mm MKIII TiUnite Implant, Brånemark Implant System, Nobel Biocare Services) with minimal to no marginal bone loss in the right central incisor position, while left central and lateral incisors presented root canal treatment, metal posts and cores, and apicoectomies sealed with amalgam fill-ins. In addition, periapical radiolucency and apical root resorption was noted in the right lateral incisor, and the left central incisor presented mesial and distal widening of the PDL together with a probing pocket depth of 4 to 5 mm. The left lateral incisor also presented periapical radiolucency (Fig 8).

Treatment plan options were established and presented to the patient. Due to the absence of sufficient bone width and height, as well as the presence of periapical pathology in lateral incisor areas, as determined by CBCT radiographic examination, the patient elected extraction of the maxillary left central incisor and right and left lateral incisors and replacement of missing teeth with an implant-supported fixed partial denture prosthesis. Final restoration of the maxillary anterior teeth was done with an implant-supported zirconia-ceramic (veneering technique) implant-supported, hybrid, screw-retained fixed

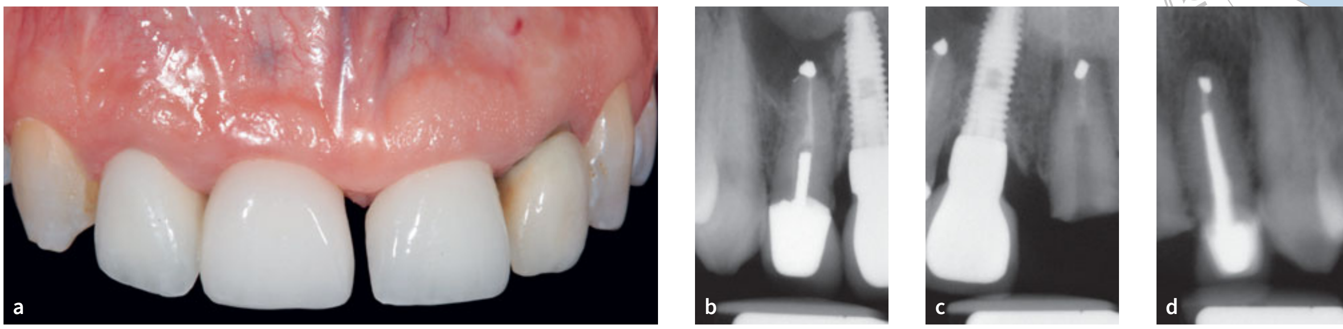

Fig 8a to d Case 2. *(a)* Pretreatment frontal view of maxillary anterior teeth. Diastema between central incisors, excessive brightness and value of incisors, as well as gingival retraction and color discrepancy of left lateral incisor, were the main complaints of the patient. *(b)* Pretreatment radiograph shows an external hex implant (13 × 4 mm MKIII TiUnite Implant, Brånemark Implant System) with minimal to no marginal bone loss in the right central incisor position. Root canal treatment, periapical radiolucency with apical root resorption, apicoectomy sealed with an amalgam fill-in, and a metal post is observed in right lateral incisor. *(c)* Radiograph of left central incisor made at the time the restoration had come loose. Image shows mesial and distal widening of the PDL, root canal treatment, metal post, and apicoectomy sealed with an amalgam fill-in. *(d)* Left lateral incisor shows root canal treatment, metal post, and apicoectomy sealed with an amalgam fill-in with periapical radiolucency.

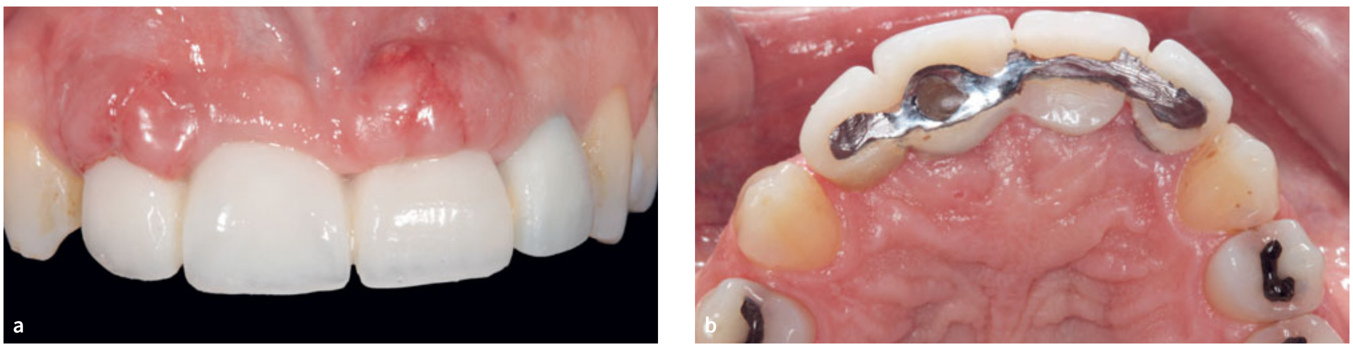

Fig 9a and b Case 2. Following teeth extractions and implant placement, a combined tooth-implant, metal-reinforced PMMA interim fixed partial denture from right lateral to left lateral incisors was immediately placed. *(a)* Frontal view of interim restoration 1 month after teeth extraction and implant placement. Buccal connective tissue grafts in right lateral and left central incisors are healing without complications. *(b)* Occlusal view of tooth-implant PMMA metal-reinforced interim fixed partial denture prosthesis. This design prevented technical complications during implant osseointegration and soft tissue maturation.

partial denture bonded to TiN bases, supported by two implants in both central incisors.

The first restorative phase included extraction of the maxillary right lateral incisor, debridement of the socket with surgical curettes to remove any remaining soft tissue, and placement of a bioresorbable collagen membrane (Biocollagen, Bioteck, Stab Prod).[39,40] In addition, extraction of the maxillary left central incisor was performed together with the simultaneous placement of a 13 × 4 mm external hex implant (MKIII TiUnite Implant, Brånemark Implant System, Nobel Biocare Services). Lack of sufficient primary stability (as determined by insertion torque) precluded the use of an immediate provisionalization protocol, therefore a two-stage surgical protocol was followed, during which a transmucosal healing abutment was connected to the implant. Following healing abutment connection, biocollagen was placed on the extraction sites of the right lateral incisor and covering the transmucosal healing abutment in the central incisor's position. Simultaneous connective tissue grafts were placed in the buccal aspect of the right lateral and left central incisor extraction sites in order to improve buccal peri-implant soft tissue thickness.[41]

Due to the patient's request to avoid the use of any kind of removable partial denture prosthesis during the provisional phase, following teeth extractions and implant placement, a

Fig 10 Case 2. Frontal view of fully implant-supported interim restoration. Soft tissue maturation is completed 8 months after surgical intervention and left lateral incisal extraction. Teeth size and height/width proportion is incorrect at this moment; however, this was corrected in the final restoration.

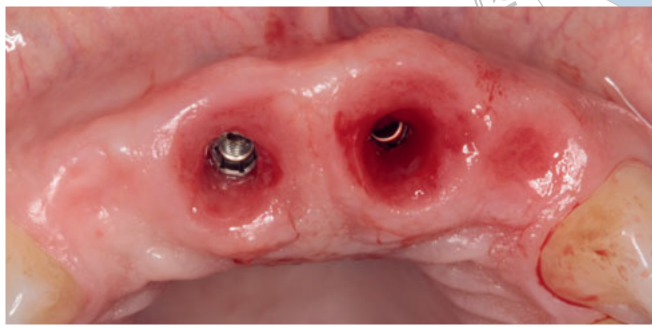

Fig 11 Case 2. Occlusal view of peri-implant soft tissues and pontic areas after interim restoration removal, prior to final impression procedures. Slight peri-implant soft tissue inflammation is noted around both implants. Adequate buccal soft tissue thickness in pontic areas and implant sites will improve the peri-implant soft tissue stability, long-term prognosis, and esthetic outcome of definitive restoration.

combined tooth-implant, metal-reinforced, PMMA interim fixed partial denture from the right lateral to left lateral incisors was fabricated and immediately placed. The provisional restoration was screwed (at implant level) in the right central incisor implant, and a non-eugenol interim cement (TempBond NE, Kerr) was used to cement the provisional fixed partial denture on the left lateral incisor. This concluded the first phase of the restorative treatment (Fig 9).

Six months were allowed for implant osseointegration and soft tissue maturation. The second phase of treatment was then initiated. This included extraction of the left lateral incisor and alveolar crest preservation. In addition, the interim tooth-implant-supported polymethyl methacrylate (PMMA) fixed partial denture was modified to incorporate the implant in the left central incisor, thereby transforming it into a fully implant-supported, screw-retained, interim, fixed partial denture prosthesis. Two months were allowed for soft tissue maturation, after which the final restoration was planned (Fig 10). Due to the thick gingival phenotype, high esthetic expectations of the patient, and the advantages of a retrievable restoration, a screw-retained, CAD/CAM hybrid abutment, implant-supported zirconia-ceramic (veneering technique) fixed partial denture bonded to TiN bases was fabricated and supported by two implants in both central incisors.

The same clinical procedure as Case 1 for shade selection and communication with the dental technician was followed. Preliminary digital photographs with Vitapan 3D-Master Shade Guide and Vita Classic Shade Guide (Vita Zahnfabrik) were used with standard exposure and cross-polarized light filter technique.

The implant-level final impression was made using the pick-up impression technique with a custom tray using the one-step, double mix, impression technique with a vinyl-polyether silicone impression material (EXA'lence 370, GC) (Fig 11). Following the same manufacturing process as in Case 1, fabrication of the final implant-supported CAD/CAM screw-retained hybrid-abutment fixed partial denture bonded to TiN bases was done. The TiN titanium bases (TiN-base Custom Interface System, IPD Dental Group) were provided by the CAD/CAM manufacturer and included the following features: 2.5-mm finish line height, 7-mm post height, and horizontal helicoidal retentive features. After the final restoration design was completed by means of CAD software (Exocad), the ceramic mesostructure was milled using a pre-sintered zirconia block (IPS e-max ZirCAD, MO, Ivoclar Vivadent). Sintering and crystallization of the zirconia mesostructure was done according to the manufacturer's recommendations. After veneering the zirconia mesostructure with feldspathic porcelain (Creation, Willy Geller International), the ceramic restoration was temporarily fitted to the TiN bases with cyanoacrylate adhesive for initial bisque-bake try-in (Fig 12).

The prosthesis soft-tissue adaptation, teeth anatomy, and color were evaluated clinically at initial bisque-bake try-in. The final design, emergence profile, anatomical contours, surface texture, and polishing were performed according to the clinician's indications. Definitive restoration was completed following the same bonding procedures as in Case 1. Prior to the restoration's final clinical insertion, the zirconia-ceramic mesostructure was bonded to the TiN base according to the following protocol:

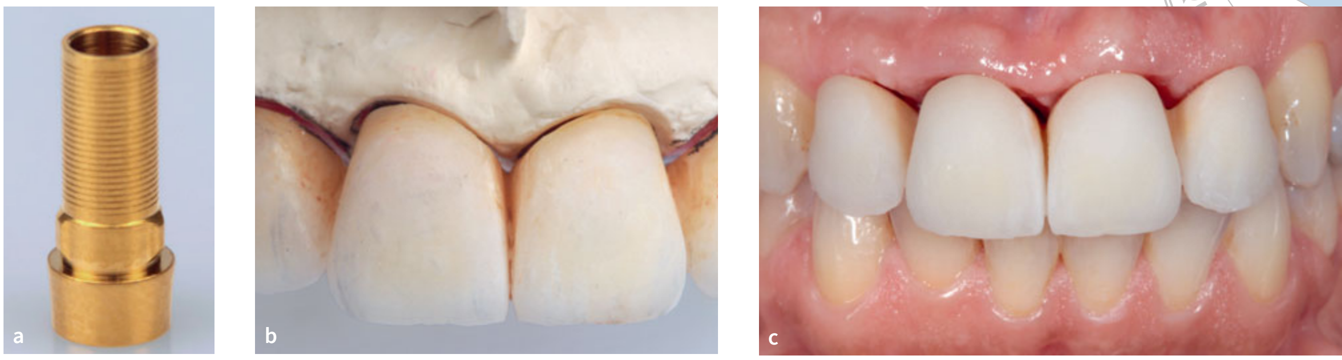

Fig 12a to c Case 2. *(a)* A 2.5-mm finish line height TiN-base was used to fabricate the zirconia-ceramic fixed partial denture. *(b)* Frontal view of initial bisque-bake fixed-partial denture on master cast prior to clinical evaluation. *(c)* Preliminary clinical evaluation of esthetic integration of implant-supported fixed partial denture. Additional porcelain is needed to improve soft tissue support and width/length ratio of restoration.

Fig 13a to c Case 2. *(a)* Frontal view of completed prosthesis on master cast. *(b)* Tissue surface of completed prosthesis. A favorable 3D position of both implants allowed designing a screw-retained implant-supported fixed partial denture without the need of using the ASC concept, as in Case 1. *(c)* Definitive implant-supported fixed partial dental prosthesis after bonding procedures were completed.

- for the titanium base, airborne-particle abrasion with 50 µm Al_2O_3 at 2.5 bar at 10-mm distance + Monobond Plus for 60 seconds
- for zirconia-ceramic mesostructure, Monobond Plus for 60 seconds.

Bonding procedures were completed using a thin layer of a dual-polymerizing composite resin cement (Panavia F 2.0, Kuraray) for cementation of the zirconia-ceramic mesostructure on the TiN base (Fig 13).

During clinical insertion, pressure indicating paste (PIP), (Keystone Industries) was applied on the tissue surface of the pontics to evaluate tissue pressure, patient compliance, as well as tissue accommodation, displacement, and emergence profile of the lateral incisors.[42] The restoration was then inserted, and abutment screws were torqued to 25 Ncm following the manufacturer's recommendations. The screw access channel was sealed with PTFE tape and microhybrid composite resin (Fig 14).

Clinical outcomes

Using a clinical outcome evaluation protocol for implant-supported restoration recently published by the present authors,[43] both patients were recalled for follow-up examination. The restorations' clinical outcomes were evaluated using magnifying glasses (magnification of 3.5 ×) and consisted of biologic parameters, esthetic clinical outcomes, technical complications, and radiographic evaluation after the 6-year clinical follow-up examination in patient 1 and 2.5-year follow-up in patient 2.

Biologic evaluation

The biologic parameters included:

- Plaque Index (PI),[44] which was assessed using a four-point scale (0, no plaque; 1, detectable plaque present upon probing; 2, moderate plaque present upon probing; 3, 1- to 2-mm thick plaque present in vestibular and interproximal spaces)

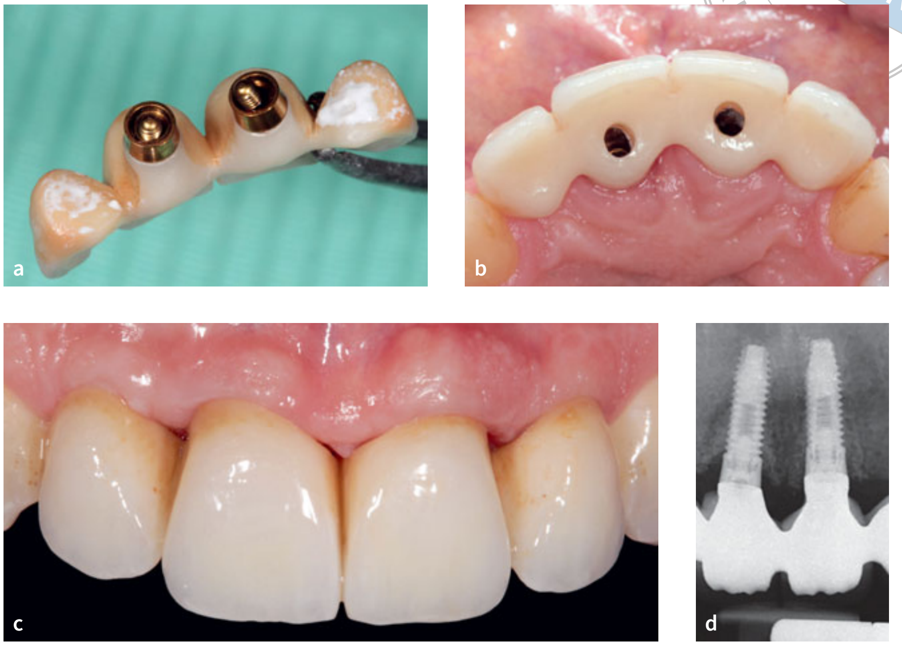

Fig 14a to d Case 2. *(a)* PIP was used to evaluate pontic tissue pressure on edentulous areas. Areas of excessive pressure are easily adjusted with high-speed hand piece and a medium grain diamond bur. *(b)* Occlusal view of fixed prosthesis in place with screw access channels in cingulum area which avoided the use of the ASC technical protocol. *(c)* Frontal view of final implant-supported fixed partial denture. Proper treatment planning and execution of different surgical and restorative phases led to a satisfactory end result. *(d)* Two-month post-insertion radiograph shows marginal bone stability and accurate fit between implants and Ti bases.

- probing pocket depth (PPD) measured in the implant restorations, from the mucosal/gingival margin to the bottom of the probeable pocket using a periodontal probe to nearest 0.5 mm at four sites of the restoration (mesial, distal, buccal, and lingual)
- bleeding on probing (BoP) assessed as absent (0) or present (1) in the implant-supported restoration
- level of oral hygiene (OH), determined according to a four-point scale (1, excellent; 2, good; 3, poor; 4, very poor)
- signs of mucositis/peri-implantitis (Ms/Ps)[45]: mucositis was defined as probing depth ≥ 4 mm and BoP, and peri-implantitis was diagnosed if bone loss ≥ 1.8 mm or three implant threads after 1 year was also present.

Esthetic evaluation

The esthetic outcome was analyzed using a four-point esthetic score (ES) defined as: 1, excellent; 2, good; 3, poor; 4, very poor. An evaluation of the gingival zenith position (GZP) was assessed by measuring from the most apical aspect of the buccal-gingival restorative margin to the incisal edge of the prosthetic crown, using a periodontal probe to the nearest 0.5 mm. An assessment of the height of the mesial and distal papilla was performed using the Papilla Index Score (PIS)[46] (0, no papilla; 1, less than half of papilla present; 2, half of papilla present; 3, papilla completely fills interproximal space; 4, interproximal hyperplastic tissue present).

Technical evaluation

The technical complication evaluation consisted of recording data on the wear of the veneering porcelain (no wear, small facet, or marked facet), abutment fracture, abutment screw loosening/fracture, veneering porcelain chipping/fracture, and/or tattooing of the gingival tissues.

Radiographic evaluation

Intraoral radiographs were made using the long-cone paralleling technique with a film holder (Rinn, Dentsply Sirona). Care was taken to ensure a clear image of the threads in both sides of the implant body. Bone levels around both implants and adjacent teeth were evaluated considering either the implant shoulder or the cementoenamel junction as the reference point, respectively.

Results

Biologic outcomes showed that tissues were maintained healthy, showing in both patients an excellent OH level (1, excellent), no detectable plaque (PI) present upon probing (0, no plaque), and no BoP (0, absent). The PPDs in patient 1 (maxillary left central incisor) were: mesial 4 mm, distal 3 mm, palatal 2 mm, and buccal 3 mm. The PPDs in patient 2 (maxillary right central incisor) were: mesial 4 mm, distal 3 mm, palatal 2 mm,

Fig 15a and b Case 1. Posttreatment clinical and radiographic evaluation in patient 1. After 6 years, clinical examination reveals excellent long-term clinical outcomes, peri-implant soft tissue integration with adjacent teeth and soft tissues, and a stable implant osseointegration.

and buccal 3 mm; and in the maxillary left central incisor, PPDs were: mesial 4 mm, distal 3 mm, palatal 2 mm, and buccal 3 mm. No signs of mucositis/peri-implantitis were detected.

Esthetic evaluation (ES) demonstrated an excellent esthetic outcome and peri-implant soft-tissue integration with adjacent natural teeth and pontic tissue areas in both patients (level 1, excellent). Posttreatment stability of the gingival zenith position (GZP) was observed, measuring 11.5 mm in the maxillary left central incisor (patient 1) and 10.5 mm in the maxillary right and left central incisors, respectively (patient 2). The PIS in patient 1 showed half of the papilla present in the distal interproximal space (level 2), whereas the mesial papilla completely filled the mesial interproximal space (level 3); in patient 2, interproximally, half of the papilla was present between both implant supported-restorations (level 2 in mesial papilla, maxillary right and left central incisors) whereas a level 1 PIS (less than half of papilla) was recorded for the distal papillas in both the maxillary right and left central incisors. In patient 1, a slight grayish area was observed in the soft-tissue apical area corresponding to the implant in the right central incisor position, compatible with a long-term thinning of the buccal bone plate. However, no observed clinical and radiographic signs of pathology were detected (Fig 15).

Neither of the two patients showed technical complications such as abutment/screw loosening or porcelain chipping/fracture/wear. The follow-up radiographic evaluation of both patients revealed a precise fit between TiN bases and the implant connecting interfaces, no marginal bone loss, and stable implant osseointegration (Fig 16).

Discussion

The present manuscript describes a novel technical and restorative protocol using the two-piece CAD/CAM screw-retained, zirconia-ceramic hybrid-abutment crown concept bonded to nitride-coated titanium bases. Biologically, the selection of the TiN bases relies in the fact that they are coated with titanium nitride. An extensive review on TiN-coated implant abutments describes how TiN-coated surfaces reduce early bacterial colonization and biofilm formation when compared to uncoated titanium surfaces.[47] Similarly, other studies also indicate that fibroblast cell proliferation, attachment, and adhesion on TiN-coated abutments is similar when compared to machined uncoated titanium abutment surfaces.[48-50] In addition, recent clinical investigations also demonstrate no significant differences in soft tissue biologic outcomes, radiographic indices, and short-term survival rates between conventional titanium, TiN-coated, and zirconia abutments.[51,52]

Biomechanically and esthetically, the clinical advantages of using TiN-coated titanium bases rely on two facts:

- from the biomechanical point of view, nitride-coated titanium abutments/titanium bases show enhanced wear resistance and abrasive hardness, low friction coefficient, and chemical inertness when compared to uncoated titanium[21,53]
- from the esthetic point of view, the main advantage of nitride-coated titanium abutments/bases is their yellow color, and their color saturation, wavelength, and reflectance has been found to be very close to that of pure gold.[13]

Although it is well known that zirconia abutment peri-implant soft tissue color and tissue integration is closest to soft tissues around natural teeth, this difference has not been considered significant when compared to gold-colored abutments such as TiN-coated abutments,[54] such the ones used with the presented restorative alternative. In fact, TiN gold color coated abutments have been demonstrated to be advantageous for abutment peri-implant soft tissue color integration,[55] espe-

Fig 16a and b Case 2. Posttreatment clinical and radiographic evaluation in patient 2. Although follow-up evaluation in this patient was done at 2.5 years of clinical function, compared to the 6-year follow-up in patient 1, clinical evaluation also revealed excellent long-term clinical outcomes, peri-implant soft tissue integration with adjacent teeth and soft tissues, and a stable implant osseointegration.

cially in the maxillary esthetic zone, when presenting a thin gingival phenotype (≤ 2 mm).[25]

Investigations evaluating the “conventional” two-piece hybrid-abutment (using standard titanium bases) concept have shown mechanical advantages and comparable fracture resistance to conventional titanium abutments.[56,57] Moreover, clinical investigations reporting on the clinical outcomes and complications of implant-supported two-piece hybrid zirconia restorations fabricated using “conventional” titanium bases show promising short-term clinical outcomes.[58,59] Nevertheless, clinical investigations on this restorative protocol also indicate the interface between the titanium base and the restoration to be the critical part, as restoration’s fractures or bonding failures have been reported.[60] On the other hand, when using TiN-coated titanium bases, a recent in vitro investigation has shown that the use of TiN bases when bonded to a zirconia ceramic restoration significantly improves the retentive forces for TiN bases (529 N) when compared to conventional titanium bases (319 N)[32]; however, this fact has not been demonstrated clinically. The present manuscript is intended to provide additional clinical information in this sense.

Other advantages of the described protocol include its design and manufacturing versatility. The proposed restorative protocol can be used with external butt joint and internal conical implant-abutment connection designs, at implant or abutment level, anterior/posterior, single/multiple unit, and full-arch implant-supported restorations, with the chosen implant system or implant-abutment connection design not playing a significant role in the short-term clinical outcomes, as described in the present manuscript. Similarly, it can also be used in two-piece CAD/CAM monolithic zirconia, screw-retained hybrid restorations, or also incorporating the use of nitride-coated titanium bases, as shown in Case 1, to the ASC technical protocol.[36] In this sense, and to the best of the present authors’ knowledge, the present report is also the first one describing the combined use of these restorative concepts.

The clinical use of two-piece CAD/CAM screw-retained, zirconia-ceramic hybrid-abutment crowns bonded to nitride-coated (TiN) titanium bases after 6 and 2.5 years of clinical follow-up shows promising clinical and radiographic outcomes. However, these are short-term clinical data shown in a reduced number of patients, which represents a limitation of the present manuscript. In contrast, and to the best of the present authors’ knowledge, there are no similar clinical reports evaluating the proposed restorative protocol. Similarly, although the current available literature evaluating clinical outcomes associated with the use of TiN-coated abutments is also scarce, mainly describing short-term clinical investigations using CAD/CAM technology for TiN abutment design and manufacturing,[28-31,55] the reported clinical outcomes are also very promising. This fact could increase the aforementioned advantages of the TiN-coated titanium bases when used in restorative implant dentistry.

Investigators have, on the other hand, also outlined concerns when TiN hard coatings are applied to metal alloys used in dentistry. Studies have shown that TiN film coatings are subjected to possible detachment from the metal substrate surface of transmucosal implant abutments.[61] Possible explanations for this delamination process include the fact that thin film coatings would adhere better on machined or airborne-particle abraded surfaces rather than on polished titanium surfaces,[26,62] or even that this phenomenon can occur due to inadequate adhesive strength between the TiN film when deposited on pure titanium.[63] However, the evidence is not conclusive due to the limited number of clinical investigations. Other reported limitations include the development of localized adverse allergic reactions associated with the use of TiN-coated transmucosal abutments. Although TiN coating is described as biochemically stable,[64] a clinical report shows TiN as being the possible cause of an allergic contact stomatitis in a patient treated with TiN-coated implant abutments used to support a fixed dental prosthesis.[65] However, 1 month after TiN-coated abutment removal and insertion of conventional titanium healing abutments, the mucosa appeared healthy and all signs and symptoms had disappeared.[65]

Additional restorative disadvantages, similarly to the conventional two-piece CAD/CAM screw-retained, zirconia-ceramic, hybrid-abutment crown concept,[66] may include:

- additional laboratory time, technical abilities, equipment, effort, and precision are needed to digitally design and manually bond the custom ceramic mesostructure on the titanium base
- the increased laboratory costs associated to the aforementioned procedures
- chipping of the veneering material.

The aforementioned favorable biomechanical properties of the conventional two-piece hybrid-abutment crown concept, together with inherent mechanical, biologic, and esthetic advantages of incorporating nitride-coated titanium bases to the original two-piece hybrid-abutment restorative concept, indicate the potential benefits of the proposed restorative and technical protocol in mechanically challenging but esthetically demanding clinical situations such as those in the maxillary esthetic zone.

Conclusions

The short-term promising clinical outcomes of the two-piece CAD/CAM screw-retained, zirconia-ceramic hybrid-abutment crown concept bonded to nitride-coated titanium bases, the advantages reported when compared to the “conventional” two-piece hybrid-abutment crown concept, and the inherent mechanical, biologic, and esthetic advantages of nitride-coated titanium bases, indicate the potential clinical benefits of the described restorative alternative in mechanically challenging but esthetically demanding clinical situations such as those in the maxillary esthetic zone.

However, the fact that in the present manuscript, the number of patients and follow-up are limited, indicates the need for additional clinical investigations as well as long-term randomized clinical trials to validate these initial observations, especially those evaluating the two-piece CAD/CAM screw-retained, zirconia-ceramic hybrid-abutment crown bonded to TiN bases when compared to the conventional two-piece hybrid design, as well as stock/custom, metal/zirconia/lithium disilicate, screw/cemented implant-supported restorations.

Disclosure

The authors have no conflicts of interest to declare.

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Rafael del Castillo

Rafael del Castillo PhD Program in Clinical Medicine and Public Health, University of Granada, Granada, Spain; and Assistant Professor, Department of Prosthodontics, Eastman Institute for Oral Health, University of Rochester, Rochester, NY, USA. ORCiD: 0000-0002-5264-3708

Carlo Ercoli Chairman, Department of Prosthodontics; Professor of Periodontology, Department of Periodontology, Eastman Institute for Oral Health, University of Rochester, Rochester, NY, USA

Rafael Valera Director, Crown and Bridge Dental Lab, Madrid, Spain

José María Díaz Fernández Professor, Department of Dentistry, Faculty of Health Sciences, Universidad Europea de Valencia, Valencia, Spain

Miguel Padial-Molina Associate Professor, Department of Oral Surgery and Implant Dentistry, School of Dentistry, University of Granada, Granada, Spain. ORCiD: 0000-0001-6222-1341

Javier Ata-Ali Professor, Department of Dentistry, Faculty of Health Sciences, Universidad Europea de Valencia, Public Dental Health Service, Conselleria de Sanitat Universal i Salut Pública, Generalitat Valenciana, Valencia, Spain

Correspondence: Rafael del Castillo, PhD Program in Clinical Medicine and Public Health, University of Granada, Granada, Spain; and Assistant Professor, Department of Prosthodontics, Eastman Institute for Oral Health, University of Rochester, Rochester, NY, USA.
Email: rdelcastillo@correo.ugr.es, casher@infomed.es

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