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CLINICAL ARTICLE

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Translucent monolithic zirconia titanium-supported FP1 full-arch prosthesis: A novel proof of concept to address esthetic, functional, and biologic challenges

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Abstract

Objective: Despite the wide clinical use of translucent zirconia for full-arch implant prostheses, reduced flexural strength and fracture toughness compared with high-strength opaque zirconia needs to be addressed. A novel proof of concept for FP1 full-arch prosthesis featured by translucent monolithic zirconia and titanium framework was presented.

Clinical Considerations: Computer-guided implant planning and surgery were executed and digitally designed FP1 temporary prosthesis prefabricated. Implant and prosthetic placement were achieved with a set of three-dimensional (3D)-printed templates. Implants were immediately loaded. After 4 months intraoral optical scan was taken to record implant coordinates, soft tissue anatomy, and temporary FP1 prosthesis. A novel digital workflow was used to design and mill overlaying translucent zirconia and anatomically shaped titanium framework with a scalloped soft-tissue interface. Final FP1 prosthesis was assembled cementing zirconia jacket on titanium counterpart.

Conclusions: Translucent zirconia supported by titanium framework can address esthetic and mechanical requirements of FP1 full-arch prosthesis, minimizing risk of fracture and providing a rigid and passive joint with supporting implants. The smooth and highly polished titanium surface with an anatomic design, tightly matching scalloped soft tissue interface, can limit food impaction, air and saliva leakage and contribute to overall biologic integration of FP1 full-arch prosthesis.

Clinical Significance: Translucent monolithic zirconia featured with anatomically shaped titanium framework with scalloped transmucosal part, combining a pleasant esthetic outcome with increased flexural strength and fracture toughness, may be indicated to increase the clinical performance of FP1 full-arch prosthesis.

KEYWORDS
dental implant, digital workflow, FP1, full-arch, immediate loading, titanium framework, zirconia

1 | INTRODUCTION

The interarch restorative space analysis in relation with the dentofacial esthetics constitutes one of the most important factors in the decision-making for full-arch implant-supported fixed dental prosthesis (FDP).[1] The 3D relationships between the jaws, the lip–tooth-ridge interplay and the clearance between implant or abutment levels and the ideal occlusal plane, dictate the prosthetic design.[2–5]

In the 1989, Carl Misch proposed a classification based on three prosthetic designs for implant-supported full-arch FDP: FP-1, FP-2, FP-3.[6] FP-1 was described as a prosthesis with a life-like appearance and natural tooth proportions, it replaces only the crown of the missing dentition and it is indicated in case of minimal loss of soft and bone tissues architecture. FP-2 was suggested in case of minimal to moderate loss of anatomy, it replaces the crown and a portion of the root. The overall design of the FP-2 prosthesis appears normal in the occlusal half, while is elongated or hyper contoured in the gingival half. FP-3 was designed to restore the dental crowns and the missing soft and bone tissue architecture of the edentulous arch, and it is featured with a pink prosthetic flange tightly adhered on the ridge. The FP1 and FP2 prostheses are characterized by a natural emergence from the soft tissue that has to be sculpted to create a scalloped interface to embrace the prosthetic emergence. The FP3 prosthesis, restoring the white and pink parts of the missing dentition, looks more artificial and rest on the soft tissue with a flat-to-flat interface. For a feasible and esthetically pleasant FP-1 prosthetic outcome, a comprehensive plan has to be executed and the surgical and prosthetic treatment initiated prior to an excessive anatomic loss.[7,8]

Inadequate interarch clearance with full-arch implant-supported FDP can result in mechanical, biologic, and esthetic complications,[9,10] as such, clinicians often reduce bone free-hand in an empiric manner to increase the restorative space.

Computer guided implant surgery can be a valuable tool for full-arch rehabilitation, to place implants in an ideal position to allow an emergence from the soft tissue interface with a natural looking, pink-free FP1 FDP.[11] In this article, a novel digital-assisted proof of concept for FP1 full-arch prosthesis featured by translucent monolithic zirconia and titanium framework was presented and executed by means of a set of stackable computer-aided design/computer-assisted manufacturing (CAD/CAM) surgical guides.[12] This digital workflow allowed the clinicians to minimize and accurately obtain the prosthetically driven bone sculpting, immediately place prosthetically driven implants, and load a prefabricated provisional that replicates digitally predetermined tissue contour.[13–15]

The porcelain-veneered zirconia full-arch FDP versus a resin-metal prosthesis, in medium-term studies, offers a high survival rate and low mechanical complication rate, reduced laboratory costs, superior durability and wear characteristics, enhanced fit due to digital fabrication, retrievability due to the availability of a digital file for duplication in the future, acrylic try-for adjustment and approval, and reduced plaque and biofilm accumulation.[16–18]

One of the most significant advantages of yttria-stabilized zirconia is its biocompatibility. The material's surface characteristics allowed for a highly polished surface that promotes excellent cell adhesion, thus playing an important role in maintaining scalloped gingival architecture for FP1 prosthesis.[19]

High-strength opaque zirconia offers enhanced mechanical properties for implant restorations, but development is needed to optimize esthetics. To overcome the aforementioned problem translucent monolithic zirconia just stained on the surface or with a minimal buccal ceramic veneering has been introduced for full-arch implant FDP, as an alternative to opaque zirconia and metal-ceramic, due to its excellent esthetics, mechanical properties, biocompatibility, and compatibility with the digital workflows.[20]

Despite wide clinical use of translucent zirconia for full-arch implant prostheses, with increased translucency of the material its flexural strength and fracture toughness is greatly diminished, which may lead to an increased incidence of prosthesis fracture compared to high-strength opaque zirconia and this side effect needs to be addressed.[21,22]

The development of CAD/CAM software and technologies allowed to digitally manage the design of the final prosthesis to combine two diverse materials, as an overlaying monolithic translucent zirconia and a metal substructure.[23–29]

The zirconia and titanium transmucosal surface characteristics allowed for a highly polished interface, that exhibited lower surface free energy and lesser surface wettability, reducing bacterial adhesion,[30] promoting excellent cell adhesion, thus playing an important role in maintaining gingival architecture for FP1 prosthesis.

To the best of our knowledge the digital workflow for the execution of an FP-1 CAD/CAM prosthesis featured by a monolithic translucent zirconia superstructure supported by a titanium framework with an anatomically scalloped transmucosal part has not been described in the scientific literature yet. Consequently, the aim of the present clinical technique article was to present the related step-by-step digital, clinical and laboratory workflow.

2 | MATERIALS AND METHODS

A 48-year-old male patient presented to the clinic with a chief complaint of an unsatisfying smile appearance, limited masticatory function and pain while chewing. The patient was in a good general health with a noncontributory medical history, except for smoking of ≤8 cigarettes per day using a tobacco heating system. Clinical and radiographic examinations revealed rampant caries, nonrestorable teeth, soft tissue inflammation, tooth mobility, residual roots and missing teeth. The patient was diagnosed with a generalized periodontitis (Stage IV, Grade b; Figures 1A,B and 2). The patient signed a comprehensive format of informed consent and agreed to be enrolled in this proof of concept clinical technical report.

An artificial intelligence-based digital smile design software (SmileCloud, Timisoara, Romania) automatically selected a personalized facially driven tooth library that was used to perform an initial virtual wax-up through a CAD/CAM software (Dental System, 3Shape, Copenhagen, Denmark). Due to the insufficient initial bone a staged approach was followed. In the first stage, all the remaining teeth in the upper jaw were extracted, except from the two canines, strategically maintained to support a full-arch transitional FDP.[31,32] Socket preservation procedures were performed, and a xenogeneic collagen matrix placed to seal the extraction sites. In the same appointment a bilateral sinus augmentation procedure was executed with a transcrestal approach and a lateral surgical access on the right and left side, respectively.[33] A mix of mineralized bone allograft (Maxgraft,

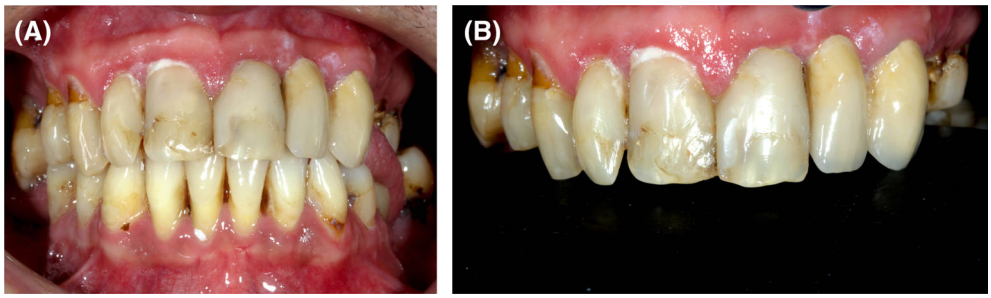

FIGURE 1 Preoperative clinical views: (A) Frontal view in occlusion; (B) close-up view of the maxillary anterior teeth.

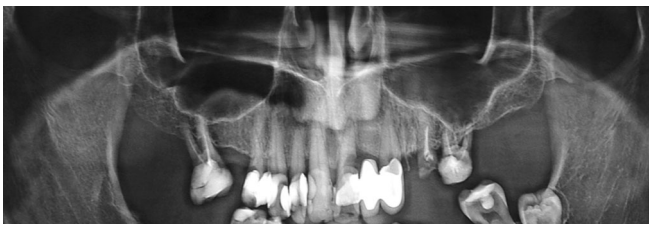

FIGURE 2 Super Pano extracted from the preoperative cone beam computed tomography.

Botiss) and of deproteinized bovine bone mineral (Cerabone, Botiss) particles, in a ratio of 50–50, was used. A 8-unit provisional FDP supported by 2 canines and with the premolars in cantilever was milled out of a disc of polymethyl-methacrylate (PMMA) (TelioCad, Ivoclar) and immediately delivered with anatomically designed pontic sites going through the extraction socket for 3 mm from the gingival margin.[34,35] (Figure 3A,B).

Six months after the bone augmentation, a cone beam computed tomography and an intraoral optical scan (IOS) impression (Trios 3, 3Shape) were taken. An implant planning software (MGuide, MIS) was used to create the virtual patient and facilitate the prosthetically driven planning and placement of seven implants (V3, MIS; Figure 4A,B. A digitally designed and milled PMMA (Telio Cad LT, A2, Ivoclar) FP1 temporary prosthesis was prefabricated with customized prosthetic channels to house the temporary cylinders and facilitate the chairside relining. The transmucosal part was digitally designed considering the virtual wax up and, the soft tissue architecture superimposed to the bone anatomy, in order to facilitate the sculpting and further developing of a scalloped interface.[36] A set of surgical templates was designed and 3D printed in order to transfer the software planned implant positions into the respective recipient sites through a fully guided surgery and drive the positioning of the prefabricated prosthesis in the patient mouth in the same coordinates as it was designed in the software. (Figure 5A–C).

The first surgical template (base guide) was used to prepare the anchor screws recipient sites. Then, the second surgical template (implant guide) featured with the same anchor-screw sleeves of the base guide, was secured in the patient mouth and used to guide the implant drilling and placement. A surgical primary stability ≥35 Ncm was achieved for each implant (Figure 6A,B). After the removal of the implant guide, multiunits abutments and then temporary cylinders were secured to the implants with a torque of 20 Ncm. The third template (prosthetic guide) was used to place the prefabricated FP1 temporary prosthesis in the same coordinates as digitally designed to facilitate the engagement of temporary cylinders and guide the scalloping of the bone. A flowable composite (Tetric, A2, Evoflow, Ivoclar) was injected in the prosthetic channels after treating the prosthetic intaglio surface with sandblasting and phosphate monomer primer (Monobond Plus, Ivoclar) to secure the temporary cylinders and reline the temporary prosthesis. A rubber dam foil was used to isolate the field during provisional FDP reline, after being properly trimmed and adapted around the base of each temporary cylinder. After curing the excess of composite were removed chairside, the emergence profiles further developed, and transmucosal surface mechanically polished. The FP1 temporary prosthesis was screwed on the multiunit abutments at 15 Ncm and the patient discharged with instruction for postoperative medications, diet, and recall schedule appointments (Figure 7A–C). After 3 months, soft tissue sounding at the pontic sites was executed, bone and gingival architecture further scalloped and transmucosal surface of temporary prosthesis refined to be in full contact with the tissue interface to limit any food impaction and air and saliva leakage.[32] (Figure 8A,B).

After 4 months, IOS impression was executed and a digital dataset created superimposing soft tissue, implant scan bodies, antagonist and temporary prosthesis scanning files. To avoid any inaccuracy in scalloped interface reproduction due to the quick collapse of the gingival tissue, FP1 temporary prosthesis was scanned both intraorally and extraorally, to capture its overall contour and in particular the transmucosal surface at the pontic sites and emerging profiles.[37] Due to the current limitations of the IOS scan for implant full-arch impression,[38] a dissected digitally designed and sintered cobalt-chromium (Co-Cr) bar was connected intraorally with low-shrinkage self-curing acrylic resin (Pattern Resin LS, GC; Figure 9A,B). The splinted bar was used to verify the 3D printed master cast accuracy. The metal bar was seated and screwed to 1 implant analogue per time to verify the passive seating onto the master cast. One implant laboratory analogue was removed from the model, connected to the splinted metal bar, and repositioned into the model after having adjusted the recipient site to achieve a passive seating and screwed the bar to all the other analogues.

A metal substructure was digitally designed (Dental System, 3Shape), taking into consideration the functional and esthetic virtual wax-up and emergence profile as it was shaped by FP1 temporary prosthesis, slightly overextended of about 1 mm to achieve an active

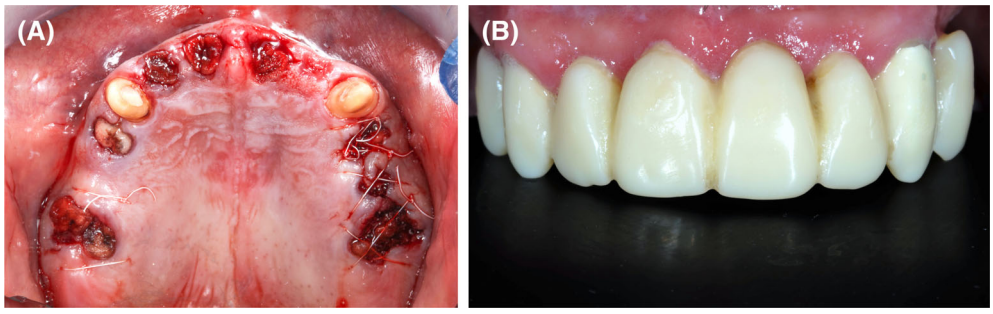

FIGURE 3 (A) First surgical stage: tooth extraction, socket preservation, socket seal with collagen matrix. (B) Close-up view of the provisional FP1 prosthesis 2-week after at the removal of the sutures.

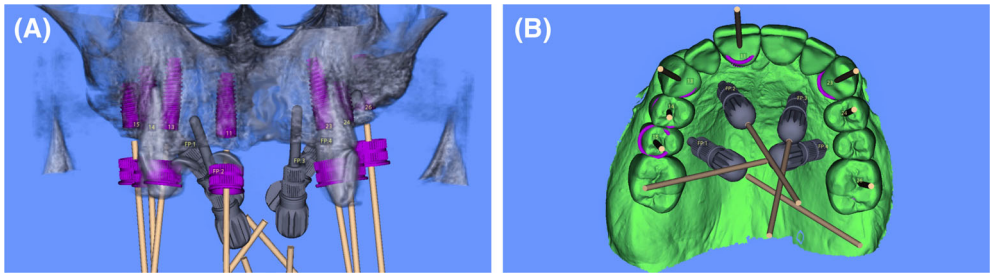

FIGURE 4 Implant planning for guided surgery: (A) Frontal view of the upper jaw anatomy and (B) occlusal view with virtual wax-up.

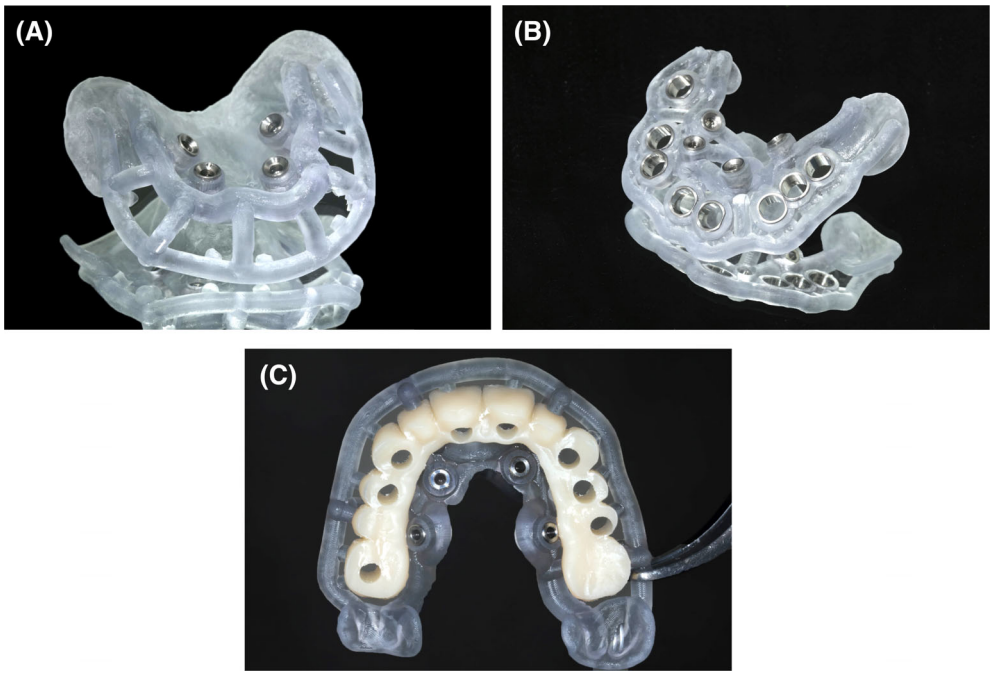

FIGURE 5 Set of stackable computer-aided design/computer-assisted manufacturing guides. (A) Base guide for anchor pin drilling. (B) Implant guide. (C) Prosthesis guide.

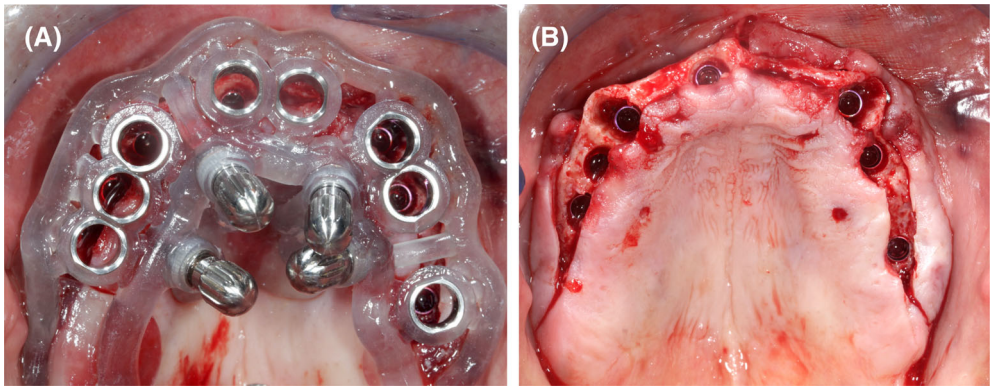

FIGURE 6 (A) Implant placement through the surgical guide. (B) Occlusal view after the removal of the guide.

FIGURE 7 Guided positioning of the provisional FP1 by the prosthetic guide. (A) Occlusal view. (B) Frontal view. (C) FP1 immediate loading.

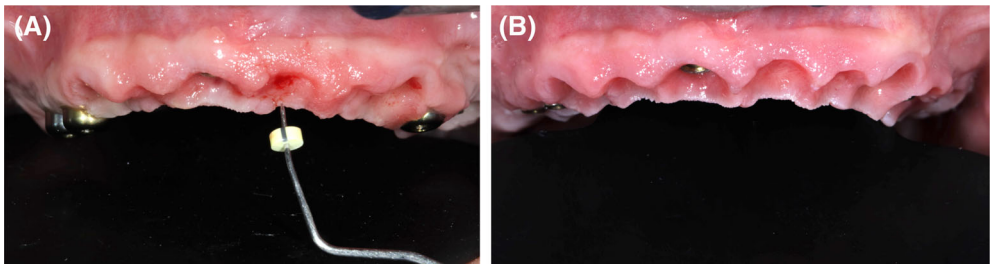

FIGURE 8 (A) Bone sounding of pontic areas 3-month after surgery. (B) Final Scalloping of the soft tissue architecture.

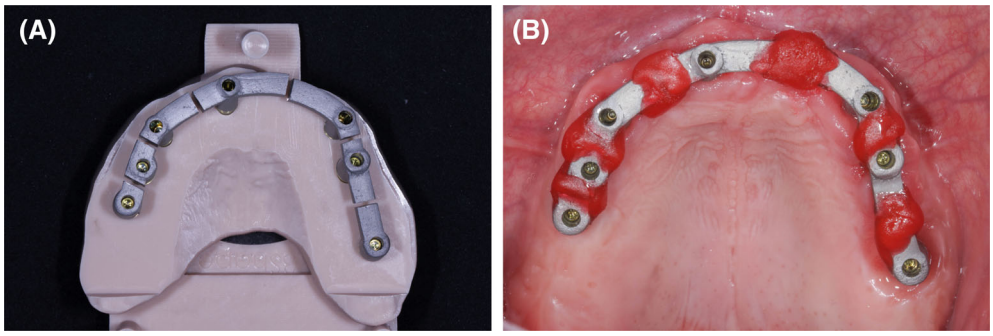

FIGURE 9 Verification of final digital impression using a segmented digitally designed and sintered cobalt chromium (Co-Cr) bar. (A) Segmented Verification jig onto the model. (B) Verification jig connected intraorally with low shrinkage acrylic resin.

pressure contact on the soft tissue interface and compensate for any loss during mechanical polishing. The metal substructure was anatomically shaped at the gingival and occlusal sides in order to be tightly adhered at the soft tissue interface, leaving at least 2 mm of clearance for the zirconia superstructure. Therefore, the overlaying zirconia superstructure was digitally designed to fit the metal substructure, accomplish a flawless finish line, avoid any undercuts, verify the path of insertion and thus facilitating the bonding procedures. (Figure 10A–E).

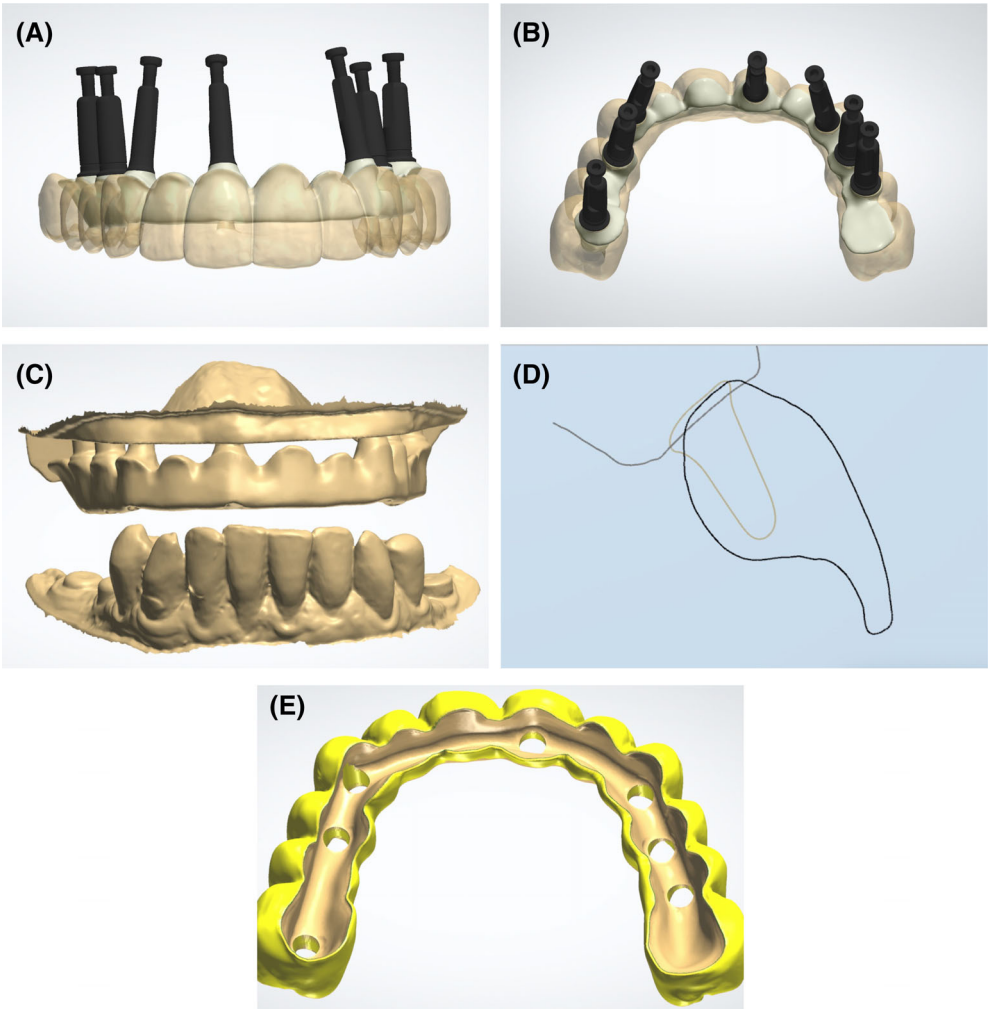

FIGURE 10 Digital design of final FP1 prosthesis (A) Frontal view. (B) Transmucosal surface with titanium substructure and zirconia superstructure anatomically shaped to be tightly adhered to the scalloped tissue interface. (C) Anatomically shaped titanium substructure transmucosal surface mirroring the tissue scalloping. (D) Cross-sectional view showing the over extension through the soft tissue to achieve an active pressure and compensate for any loss during the final mechanical polishing. (E) zirconia superstructure digitally design avoiding any flawless finish line towards the titanium substructure, considering the insertion path and avoiding any undercuts.

Finally, the inclination of the screw access holes was digitally adjusted to end up in the occlusal area, dedicated angulated screw channel prosthetic screws were used and metal substructure was milled out of a titanium block (Colado CAD Ti5, Ivoclar-Vivadent). The titanium framework passive fit was further verified intraorally and final occlusion and esthetics adjusted by a 3D printed resin protype (DentaTry, Asiga) fitted over the titanium substructure and secured with a temporary cement (TempBond Clear, Kerr; Figure 11A–C).

Based to the digital design, a zirconia overlay was milled, and 3D stained. (IPS e.max ZirCad Prime). A graded zirconia was used, featured by polycrystalline 3yttria-stabilized tetragonal zirconia (3Y-TZP) at the dentin side of the disk and 5Y-TZP zirconia at the incisal side. This specific type of zirconia combined the mechanical characteristics of 3Y-TZP opaque zirconia (flexural strength disclosed by the producer 1200 MPa) with the esthetics of 5Y-TZP translucent zirconia (flexural strength disclosed by the producer 650 MPa). The titanium substructure was anatomically designed to leave a clearance of at least 2 mm for the zirconia superstructure at the occlusal and connector sides.[39] The intaglio surface of the zirconia superstructure was air abraded utilizing 50-μm Al_2O_3 particles under a pressure of <2 bar at a distance of 2 cm. Subsequently, the metal counterpart that had to be bonded to zirconia superstructure was air abraded utilizing 110-μm Al_2O_3 particles under a pressure of 2.5 bar.[40,41] A coating of glycerin gel was applied to the surfaces of both structure that had to be protected from the effect of the airborne-particle abrasion and in particular the transmucosal part. After a thoroughly rinse and air dry of the two parts of the prosthesis, the next step included the application of a zirconia primer (Z-Prime Plus, Bisco) and a metal primer (Alloy Primer, Kuraray) on the respective surfaces, then air dried by heated air. Finally, the zirconia superstructure was bonded with the titanium substructure using a self-curing luting composite (Multilink Hybrid Abutment, Ivoclar). After the bonding procedure, any remnants at the interface between the two counterparts were mechanically removed and the surface polished (LUS85, Meisinger; Figure 12). The final screw-retained prosthesis was delivered and torqued to 30 Ncm and the radiographic assessment executed (Figure 13A,B). The screw-channels were filled with medical grade polytetrafluoroethylene tape (i-PLUG, Applied Dental Inc.) and composite after having treated the zirconia surface with zirconia primer (Z-Prime Plus, Bisco) and bonding (all-Bond Universal, Bisco). After the follow-up appointments at 1, 2, and 4 weeks, patient was scheduled for periodic maintenance every 6 months. The retrievability of the final monolithic translucent zirconia titanium-supported FP1 prosthesis allowed to follow up the outcome of the interface over time. (Figures 14A,B and 15).

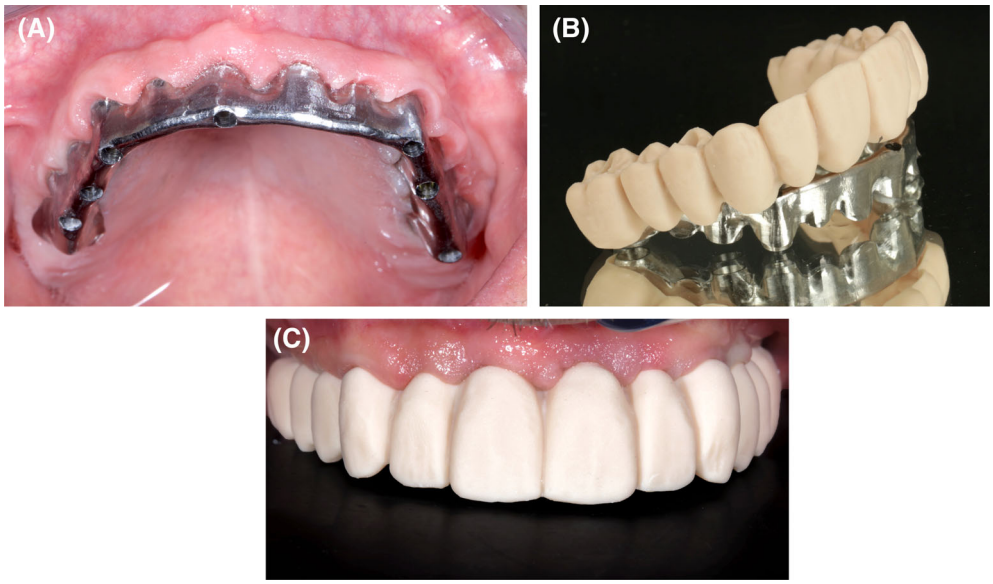

FIGURE 11 The titanium substructure intraoral verification. (A) Titanium substructure fully embraced by the soft tissue scalloped architecture. (B) Final occlusion and esthetics intraoral verification with the 3D-printed prototype.

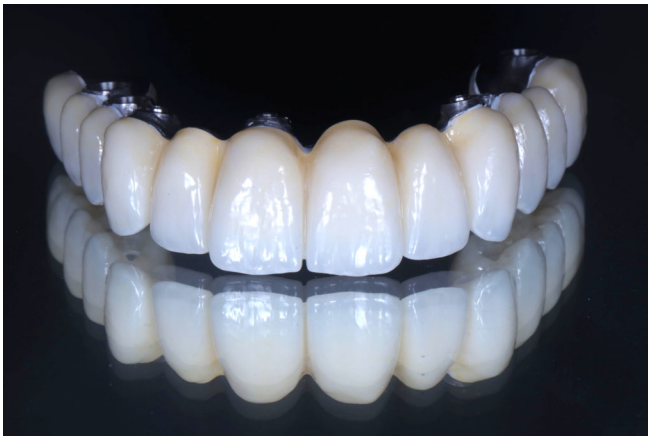

FIGURE 12 Frontal view of the final Zirconia titanium-supported FP1 prosthesis after the bonding procedures of the two counterparts. Any remnants of cement at the finish line were carefully removed and the surface polished mechanically. The final prosthesis was decontaminated in an ultrasonic bath with an isopropanol solution and after that steamed.

3 | DISCUSSION

Despite wide clinical use of translucent zirconia for full-arch implant prostheses, reduced flexural strength and fracture toughness compared to high-strength opaque zirconia needs to be addressed. To the best of our knowledge this is the first manuscript reporting on this novel proof of concept for FP1 full-arch prosthesis featured with translucent monolithic zirconia superstructure and a titanium substructure. Unfortunately, no comparative data are available on long term performance of this specific type of restoration.

Within the limitation of this technical report translucent zirconia supported by titanium framework can address esthetic and mechanical requirements of FP1 full-arch prosthesis, minimizing risk of fracture and providing a rigid and passive joint with supporting implants. One of the most significant advantages of zirconia is its biocompatibility. The zirconia and titanium transmucosal surface characteristics allowed for a highly polished interface that promotes excellent cell adhesion, thus playing an important role in maintaining gingival architecture for FP1 prosthesis. The development of CAD/CAM software and technologies allowed to digitally manage the design of the final prosthesis to combine two diverse materials, as an overlaying monolithic translucent zirconia and a titanium substructure. The CAD/CAM clinical and laboratory workflow facilitated the transferring of the soft tissue architecture into the software allowing to customize an anatomically shaped transmucosal zirconia–titanium prosthesis, tightly matching scalloped tissue interface, limiting food impaction, air and saliva leakage and contribute to overall biologic integration of FP1 full-arch prosthesis.

Digital technology was utilized, to perform a precise and comprehensive virtual treatment plan in which the functional, esthetic, and biologic requirements of each implant and pontic sites were meticulously addressed. The virtual teeth with the selected natural morphology were used in the digital wax up and transferred as a provisional prosthesis, immediately after the guided placement of the implants by a set of surgical templates. The accurate delivery of an immediate implant-supported provisional restoration in edentulous arches is considered as one of the most demanding procedures, due to the absence of fixed reference points to secure any type of surgical template except for the bone tissue. In the present technical report, a combination of two teeth and four palatal surgical pins was employed to provide the template stability needed to execute an accurate guided surgery and prosthetics. Particularly in FP-1 cases, where a correct emergence profile has to be formed though the implant-supported immediate temporary prosthesis, digital workflow facilitated the design and the 3D positioning of the restoration in order its transmucosal part to be oriented according to the initial virtual design.

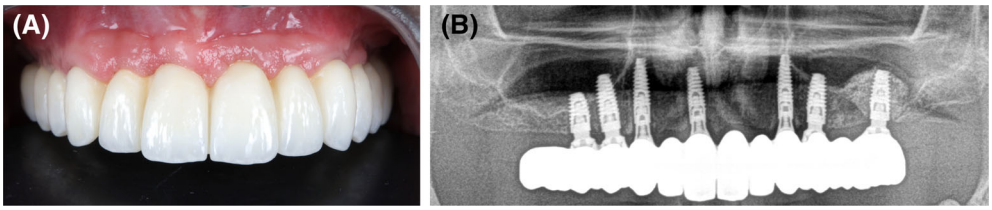

FIGURE 13 Final restoration delivered in the patient mouth. (A) Frontal view of the FP1 design fully embraced by the soft tissue architecture. (B) Radiographic assessment with the super-pano extracted by the cone beam computed tomography postoperative exam.

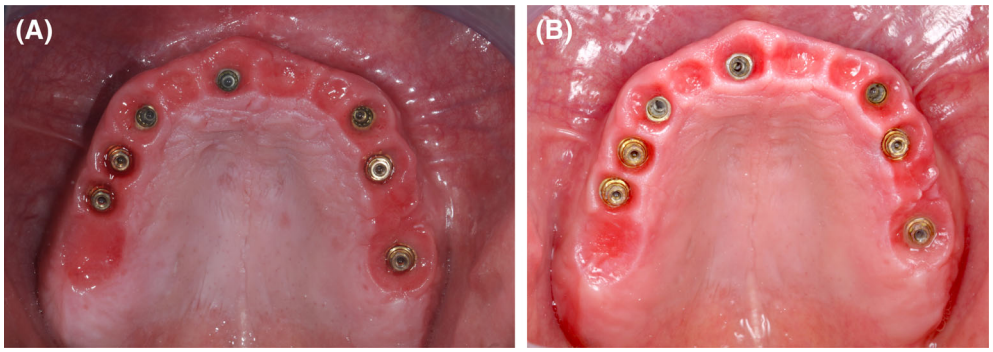

FIGURE 14 The retrievability of the final monolithic translucent zirconia titanium-supported FP1 prosthesis allowed to follow up the outcome of the interface over time. (A) occlusal view the day of the final prosthesis delivery. (B) At 1 year follow showing further soft tissue maturation and health with no bleeding.

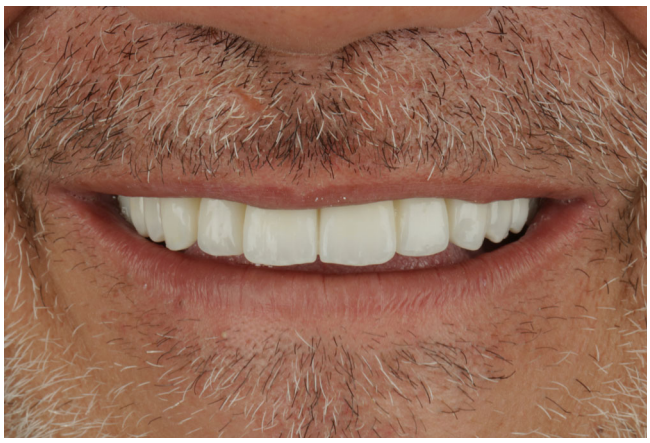

FIGURE 15 Final patient smile.

The 3D-anatomy of the transmucosal part of the provisional restoration was of paramount importance in order to create a correct emergence profile not only for implants but also for pontic areas. The emergence profile was essential for a harmonious transition between the prosthesis and the soft tissue, establishing in the same time the circumstances that are compatible with peri-implant health. In order to prevent any undue pressure, pontics have to be designed with at least a space of 2.5 mm from the level of bone. The available soft tissue thickness in order to estimate the extension of the pontic area can be measured by bone sounding, utilizing a periodontal probe or through a digital assessment.

The final implant-supported prosthesis was digitally designed and fabricated, in order to combine a monolithic translucent zirconia restoration with a titanium substructure. In FP-1 prosthesis the titanium substructure has to follow the emergence profile of the soft tissue, as it has been shaped by the immediate temporary prosthesis. For this reason, time was spent chairside to provide the FP1 temporary prosthesis with ideal contours both on implant and on pontic sites. Titanium support can offer a good rigidity to the final FP1 prosthesis, as it combines a high tensile strength and high fracture toughness.

Translucent monolithic zirconia restoration was bonded over the titanium substructure, either as one piece or as a combination of segments, to be able to individually be replaced in case of a complication. A passive fit between the substructure and the zirconia overlay is mandatory, to compensate the difference in the mechanical properties between the two materials and to reduce the need for mechanical intervention after the milling procedure. The connection between the zirconia overlay and titanium substructure can be achieved either by using a cement or by implementing separate screw channels for a screw retained overlay restoration. However, the latter solution was less feasible because of implementing separate individual screw channels for the overlay zirconia, provides easier future retrievability but demands more prosthetic space compared to a cement retained, which is difficult to be achieved in FP-1 protheses, due to limited interarch clearance and need of simulate a natural dentition. In all the clinical scenarios with potential risk factors for mechanical complications, as long spans between adjacent implants, cantilevers, limited prosthetic space or patients with a history of parafunctional habits, the reported titanium supported monolithic translucent zirconia prosthesis has to be considered. Titanium was selected for milling the substructure, due to its biocompatibility. However, this type of prosthesis required increased laboratory costs compared to monolithic zirconia restorations. Despite the promising results mostly translated from the individual well documented clinical performance of zirconia- and titanium-based full-arch prostheses, more clinical data are required with a longer follow-up time, to evaluate the daily feasibility of this novel proof of concept for FP1 prosthesis.

4 | CONCLUSIONS

Within the limitations of this technical report translucent monolithic zirconia supported by anatomically shaped titanium framework with a scalloped transmucosal part, combining a pleasant esthetic outcome with increased flexural strength and fracture toughness, and highly polished biocompatible surface may be indicated to increase the clinical performance of FP1 full-arch prosthesis.

CONFLICT OF INTEREST STATEMENT

The authors do not have any financial interest in the companies whose materials were included in this article.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

INFORMED CONSENT

Yes, human subjects were involved. Yes, I have stated that Informed Consent was obtained, or provided an explanation in my Methods section.

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