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Integration of Digital Technology, Implants, and Adhesive Dentistry for Predictable Esthetic Results in Complex Anterior Rehabilitations

The increased demand for high-quality, functional, and natural-looking restorations has driven the development of new restorative materials, technologies, and techniques. Esthetic rehabilitation that combines the advantages of implant-supported prostheses to restore missing dentition and bonding procedures to restore adjacent teeth using minimally invasive approaches allows clinicians to significantly improve esthetics and correct altered teeth shape ultraconservatively.

In the past, the main objective of an implant treatment was to ensure osteointegration,[1] which might not always presuppose a successful esthetic outcome.[2] With the development of bone grafting materials, guided bone regeneration techniques, and digital treatment planning, the concept of implant treatment has changed to "restoration-driven implant placement."[3] Consequently, there has been an increased demand for esthetic and functional restorations with healthy peri-implant soft tissue.[4] Nowadays, one of the biggest challenges in dentistry is to restore a single anterior tooth with an implant-supported restoration that mimics all lost structures as closely as possible to those of the contralateral or original tooth.[5]

The advancements in dental ceramics and adhesive technology allow ultraconservative treatments to improve esthetics and function by modifying the morphology and/or shade of anterior teeth. The main advantage of using ultrathin ceramic restorations is maximum enamel preservation, which ensures the long-term success of the restorative treatment.[6] However, some situations, such as tooth discoloration and/or malposition, may require a large amount of dentin to be exposed during tooth preparation. In such situations, the clinician should be aware that the adhesive bonding protocol must be modified to create a reliable long-term resin-dentin interface.

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Figs 1a and 1b Preoperative intraoral views. The patient is missing the maxillary left central incisor due to dental trauma, and the right central is discolored due to endodontic therapy.

Fig 2a Preoperative analysis of teeth outline and inclination. Note the flare of the teeth and inadequate relationship with the proposed midline.

Fig 2b Digital design depicting the ideal teeth proportions (width/length ratio) and inclination toward the midline. Digital analysis was used to explain the advantages and limitations of the esthetic treatment proposed.

Therefore, the aim of this article is to describe ultraconservative procedures to restore the esthetics and function of patients exhibiting discolored, missing, and misaligned anterior teeth while ensuring the appropriate longevity of the restorations.

CASE PRESENTATION

Initial Diagnosis and Treatment Planning

A 34-year-old systemically healthy nonsmoking male presented to the Advanced Operative & Adhesive Dentistry Program, Herman Ostrow School of Dentistry of University of Southern California, for esthetic treatment of his anterior teeth. The patient was missing the maxillary left central incisor due to trauma, and the right central was discolored due to endodontic therapy.

The success of esthetic and functional treatment of the anterior teeth depends on an adequate treatment plan. Photographs were taken of the patient's face with the lips in resting position as well as smiling to evaluate the lip competence and lip line position. Intraoral photographs were taken to evaluate the dental arrangement, smile line, gingiva position, occlusal planes, teeth color and shape, as well as emergence profile of the teeth (Figs 1a and 1b). A two-dimensional digital treatment planning was done using presentation software (Keynote, Apple) to facilitate interdisciplinary communication, as well as to discuss treatment options and limitations with the patient (Figs 2a and 2b).

Guided Bone Regeneration

Tooth extraction initiates various soft and hard tissue alterations that lead to a reduced alveolar ridge contour,[7] which is exacerbated if the tooth is traumatically removed.


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Fig 3 Crestal incision with vertical releases and full-thickness mucoperiosteal flap elevation to expose the alveolar ridge deficiency site.

Fig 4 Tenting titanium screws positioned strategically in the alveolar ridge deficiency to create the potential threshold for horizontal bone gain of approximately 4 mm.

Fig 5 Autogenous bone graft harvested from the retromolar area with a bone scraper.

Fig 6 Autograft bone mixed with deproteinized bovine bone mineral applied on the alveolar ridge deficiency to cover the screw heads.

Fig 7 Resorbable membrane placed over the screws and grafted site, stabilized by two tacks in the apical portion.

Fig 8 Surgical site sutured, achieving tension-free primary closure.

In order to place an implant in the correct position for a screw-retained restoration, as well as have adequate gingival architecture and esthetics, the alveolar ridge deficiency must be corrected.[8,9] Reconstruction of the alveolar bone can be achieved through many regenerative surgical procedures, including guided bone regeneration; onlay grafting; combinations of onlay, veneer, and interpositional inlay grafting; distraction osteogenesis; ridge splitting; as well as a multidisciplinary approach utilizing forced eruption.[10]

The tent screw pole technique is a safe and effective method for augmentation of bone height and width in severely resorbed ridges.[10] During the healing period, the tenting screws maintain the volume and the geometry of the space. This allows for the stabilization of the blood clot and undisturbed healing. The tenting effect facilitates successful bone augmentation with a high predictability, low risk of complications, and reduced healing period.[10] This helps prevent the soft tissues from contracting around the graft material and subsequently displacing it or causing physiologic resorption.[9]

A crestal incision with vertical releases was made and a full-thickness mucoperiosteal flap was elevated (Fig 3). Two 12-mm-long titanium screws (Trutent Tenting Screw, ACE Surgical Supply) were placed in the alveolar ridge deficiency area with approximately 4 mm of the screw exposed above the alveolus, maintaining space for the graft (Fig 4). Autologous bone was harvested from the retromolar area with a bone scraper (Fig 5). The autogenous bone chips were mixed with deproteinized bovine bone mineral (Bio-Oss, Geistlich Pharma) at a ratio of 1:1. The graft material was placed into the site until only the surface of the screws was visible (Fig 6). Then, a resorbable membrane (OsseoGuard, Zimmer Biomet) was placed over the screws and grafted site. Additional stabilization of the resorbable membrane was achieved using two tacks in the apical portion (Fig 7). The surgical site was sutured using 5/0 polytetrafluoroethylene (Cytoplast PTFE suture, Biohorizons) and 5/0 polypropylene sutures (Perma Sharp Suture, Hu-Friedy) to achieve tension-free primary closure (Fig 8).

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Fig 9 Postoperative view after 6 months of healing.

Fig 10 Anterior esthetic and functional wax-up based on the two-dimensional digital treatment planning (compare to Fig 2b).

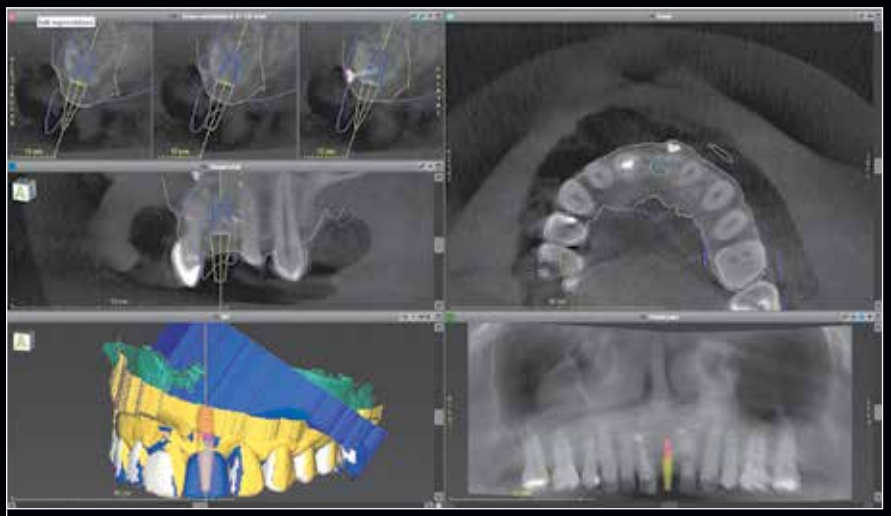

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Fig 11 Diagnostic wax-up digitalized and combined with the patient's maxillary impression and CBCT file to plan the implant placement position and angulation.

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Fig 12 Surgical guide printed with the selected implant sleeve.

Fig 13 Intraoral evaluation of the surgical guide fit.

Digital Treatment Planning for Implant Placement

After 6 months of healing (Fig 9), a cone beam computed tomography (CBCT) scan was taken to evaluate the augmented bone site. A maxillary esthetic and functional wax-up (Fig 10) was digitalized using CAD/CAM software (PlanScan, Planmeca) and merged with the CBCT scan (Fig 11) using implant planning software (coDiagnostiX, Dental Wings). The implant position and angulation were digitally determined, and a surgical guide for the implant placement was fabricated. The guide was printed and a sleeve designed for the Straumann Implant System to be used was placed on the implant access hole (Fig 12). The surgical guide fit was then intraorally verified to confirm the adaptation before the surgical implant placement (Fig 13).

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Fig 14 Vestibular incision subperiosteal tunnel access (VISTA technique) to retrieve the tenting screws.

Fig 15 Sigmoidal incision on the palatal side to gain access to the bone crest.

Fig 16 Drilling sequence for the implant placement according to the digital treatment planning.

Fig 17 Implant placed subcrestally.

Fig 18 VISTA technique of coronal gingival advancement to correct the gingival level on maxillary left side.

Implant Guided Surgery and Coronal Advancement

To minimize the surgical trauma, a vestibular incision subperiosteal tunnel access (VISTA) was used to retrieve the tenting screws.[11] Through this incision, a subperiosteal tunnel was created using a series of specially designed elevators, extending toward the vestibular depth, as well as the ridge crest (Fig 14).

After removal of the tenting screws, a sigmoidal incision was made on the palatal side to gain access to the bone crest (Fig 15). The drilling sequence was done according to the digital planning using the surgical guide and the corresponding sleeves and drill handles (Fig 16). After the implant bed preparation, a Straumann Bone Level 4.1 × 12-mm implant was inserted subcrestally with a torque of 35 Ncm (Fig 17) and a 4-mm-long RC healing abutment was placed. Lastly, using the VISTA technique, a coronal advancement was done for the adjacent lateral incisor and canine using 5/0 polypropylene suture (Perma Sharp Suture, Hu-Friedy) bonded to correct the gingival level. The vestibular incision was sutured with 5/0 PTFE suture (Cytoplast PTFE suture, Biohorizons) (Fig 18).

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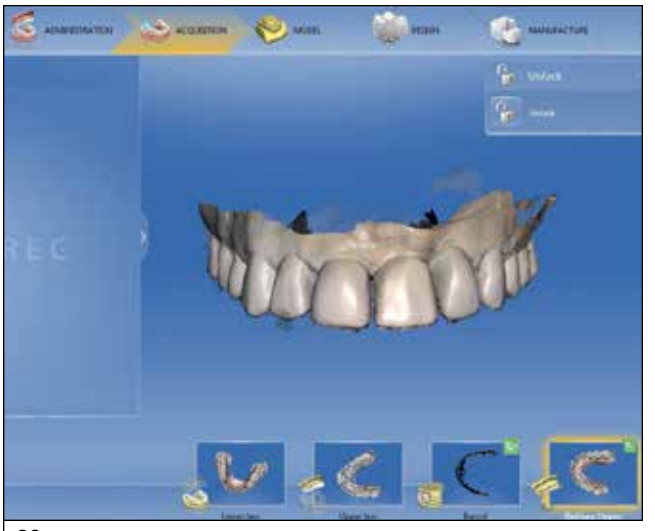

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Fig 19 Clinical aspect 4 months after implant placement and coronal gingival advancement.

Fig 20 Virtual 3D models imported into CAD/CAM designing software to fabricate the provisional screw-retained implant restoration.

Figs 21a and 21b Interim restoration milled, polished, and connected to the titanium base.

CAD/CAM Provisional Restoration Fabrication

Adequately restoring function and esthetics for implant restorations in the esthetic zone is a challenge.[12] In addition to surgical modification, soft tissue management with provisional restoration plays a crucial role in the esthetic outcome.[1] In other words, the final esthetic results of single implant restorations are influenced by the shape and position of the implant, soft tissue management during the surgery, design of the provisional restoration, type of abutment, and characteristics of the definitive restoration.[5] Therefore, to create a satisfactory esthetic treatment it is important to mimic all lost structures as closely as possible to those of the contralateral tooth.[13]

Four months after the implant placement (Fig 19), the healing abutment was removed and immediately replaced by a digital scan-post. A radiograph was taken to confirm the scan-post position, a scan-body was then placed on the scan-post, and the maxilla was scanned using an intraoral scanner (CEREC, Dentsply Sirona). The virtual 3D models of the scan-post, diagnostic wax-up, mandible, and patient's occlusion were imported into the CAD/CAM designing software to fabricate an interim implant-supported restoration (Fig 20).

The aim of a provisional implant-supported restoration is to restore the masticatory function and the contour of the peri-implant soft tissue to create an optimum emergence profile for the final restoration. The provisional restoration was designed, based on the morphology of the diagnostic wax-up, and milled in a block of microfiller-reinforced polyacrylic (CAD-temp Multicolor, VITA Zahnfabrik) (Fig 21a). The screw-retained provisional restoration was polished and bonded to the titanium base (TiBase, Dentsply Sirona) using dual-cure resin cement (Fig 21b).

Direct Gingival Recontouring

The provisional implant restoration was connected to the implant and the subgingival contours were gradually recontoured to modify the soft tissue profile around the im-

Fig 22 Interim restoration connected to the implant before subgingival recontouring.

Fig 23 Facial view of the interim restoration connected to the implant after correction of the subgingival contours.

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Fig 24 Aspects of the completed interim screw-retained restoration used to modify the soft tissue profile around the implant.

Fig 25 Customized impression coping fabricated to transfer the emergence profile contours and position of the gingiva from the interim to the final implant-supported restoration.

plant (Fig 22). The direct contouring technique allows the clinician to gradually modify the restoration while gauging the effect on the peri-implant tissues to optimize the esthetic results. Areas of residual gingival blanching that were present after 15 minutes were reduced; in areas with a lack of peri-implant tissues, pressure flowable nanofilled composite resin (Filtek Supreme Ultra, 3M ESPE) was added.[14] The modified areas of the emergence profile of the provisional restoration were then properly polished for precise soft tissue management. This approach allows the tissues to gradually adapt to the pressure, without overstressing the elasticity of the gingival tissue,[15] as well as allows soft tissue maturation and a chance for the patient to try the esthetics and function of the restoration before the final inpression.[16]

The provisional restoration was relined and reshaped three times, so that the soft tissue was managed and guided to achieve the desired emergence profile (Fig 23). Ideally, the modified emergence profile of the provisional restoration should contain two specific areas: *(1)* a concave area, about 1 mm subgingival and continuing for 360 degrees around all margins of the provisional restoration, to provide a nonsurgical increase in tissue thickness and long-term stability, and *(2)* an interproximal subgingival area that should be convex to support the papillae (Fig 24).[5] After 6 weeks, a customized impression coping was fabricated to transfer the emergence profile contours and position of the gingiva from the provisional restoration to the definitive prosthesis (Fig 25).

Shade Correction and Restoration Prototypes Try-in

Bleaching procedures should be performed before the tooth preparations to balance the shade among different teeth. The teeth were bleached using a combination of in-office and at-home techniques,[17] as well as nonvital tooth bleaching on the endodontically treated tooth. Two weeks after completion of the bleaching treatment, shade matching was done visually and with the aid of a spectrophotometer (Easy Shade, Vita), and dental photographs were taken to register the color of the hydrated teeth.

The morphology of the restoration prototypes were transferred from the waxed diagnostic cast to the patient's mouth using a polyvinyl siloxane impression filled with a chemical-cure multifunctional methacrylic ester resin (Integrity, Dentsply Sirona).[6] After the resin polymerization,

Fig 26 Restoration prototypes in the patient's mouth.

the excesses were carefully removed with a surgical scalpel blade (Fig 26). The restoration prototype try-in allowed the dentist and patient to evaluate whether the proposed esthetic and functional treatment was correct or if any adjustments were necessary. If any intraoral corrections are made, an impression of the restoration prototype must be taken after the adjustments to transfer those changes to the technician or to the CAD/CAM software. Moreover, both functional movements—anterior and canine guidance—and phonetics must be evaluated before starting tooth preparation to ensure the final restorations will not interfere with the patient's speech nor masticatory function.[18]

TOOTH PREPARATION

Before tooth preparation begins, the patient must sign a form indicating approval of the esthetics, shape, and position of the restoration prototypes. The success of ultra-thin bonded ceramic restorations requires maximum enamel preservation during the tooth preparation. When there is exposed dentin, the ceramic veneer must be thicker, at least 0.5 mm, to withstand the stresses of flexion and compression on the resin-dentin interface. Moreover, the dentin-bonded interface is susceptible to hydrolytic and enzymatic degradation, which can cause margin discoloration, secondary caries, and veneer debonding over time.[19,20]

To maximize enamel preservation, the tooth preparation must be focused on creating a path of insertion for the ceramic restorations, with evaluation of the need of reduction of the facial surface volume, teeth alignment and angulation, as well as the color of the dental substrate.[6] When the tooth shade is favorable, minimal or no tooth reduction is necessary. The tooth preparation must be done based on the contour of the final restorations, guided by the restoration prototypes, as well as vertical, horizontal, and incisal reduction guides (Fig 27).[21] Ideally, when only a minor color change is necessary, the tooth reduction should be ultraconservative, maintaining the inner enamel throughout the entire preparation.[22]

When the difference between the desired final restoration color and the tooth preparation color is one shade or more, such as from A2 to A1, the restoration thickness plays an important role in modifying the color of the substrate.[23] If the desired final color is up to two shades brighter, a facial reduction of 0.6 mm is necessary. In this situation, the final shade is a combination of the colors of the tooth substrate, resin cement, and the ceramic restoration.[23] However, when a correction of three or more shades is necessary to achieve the desired color, such as from A4 to A1, the restoration must mask the discoloration of the dental substrate. In this case, a facial and proximal reduction of 0.9 mm is necessary, and the gingival margin must be subgingival on the esthetic areas.[23]

After the teeth reduction is completed, the preparations should be polished to ensure maximum adaptation of the ceramic restoration with a reduced luting film thickness (Fig 28). Moreover, the tooth preparation stump shades must be documented using digital photography to facilitate communication with the laboratory technician.

Final Impression

The location of the gingival finishing line of the preparation will determine the need for retraction cords during the final impression. In cases when the finishing line is supragingival, the final impression should be taken without retraction cords, maintaining the gingiva in its natural position. Restorations with cervical overcontour change the natural emergence profile of the teeth, promoting plaque accumulation, gingival inflammation, and, consequently, gingival recession over time.[24]


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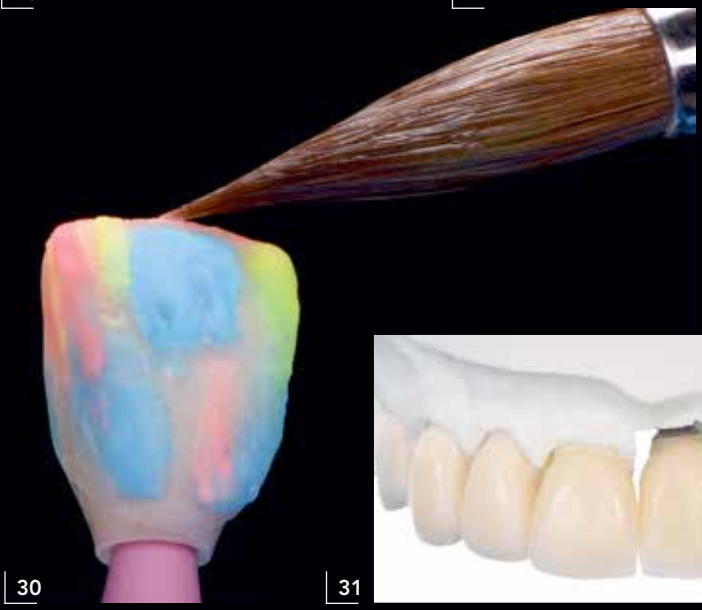
Fig 27 Tooth preparation over the restoration prototypes to ensure maximum enamel preservation.

Fig 28 Polishing of tooth preparations before the final impression is taken.

Fig 29 Customized impression coping connected to the implant, and retraction cord placed before the impression.

Fig 30 Layering of zirconia implant-supported crown with feldspathic ceramic.

Fig 31 Feldspathic ceramic–layered crown and veneer restorations after finishing and polishing.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When the tooth preparation extends subgingivally, retraction cords must be used for soft tissue displacement, exposing the preparation finishing line. In such situations, a dual-cord impression technique displaces the facial and interproximal papilla, allowing the technician to create the new emergence profile for the bonded restorations if necessary. The customized impression coping was connected to the implant and a periapical radiograph was taken to confirm the correct position. A one-step dual-cord impression technique was used for this case (Fig 29).

Provisional Restorations

The provisional implant-supported restoration was connected to the implant, and chairside provisional restorations were fabricated for the other prepared teeth. The tooth preparations were spot-etched with 35% phosphoric acid, and an etch-and-rinse adhesive was applied and light cured. The impression filled with chemical-cure multifunctional methacrylic ester resin was seated on the tooth preparations and kept in position until polymerization was complete. All excesses were removed using a surgical scalpel blade and gingival embrasures opened to allow the patient to clean the interproximal spaces with dental floss connected to a floss threader.[25]

Restoration Fabrication

Porcelain veneers were fabricated with feldspathic ceramic (Creation CC, Creation Willi Geller). The implant crown was fabricated with layered feldspathic ceramic over a zirconia implant abutment (Fig 30). The restorations were fabricated using a build-up layering technique, which allowed the laboratory technician to stratify different ceramic shades and translucency to mask the discoloration of the right central incisor. After finishing the firing cycle, a natural-looking surface morphology was created during the restoration finishing and polishing procedures (Fig 31).

32a

32b

Figs 32a and 32b Incisal and facial views of the tooth preparations and implant site after removal of the provisional restorations.

33a

33b

Figs 33a and 33b Screw-retained implant-supported crown delivered before starting the veneer bonding procedures.

Restoration Try-in and Implant Crown Delivery

The provisional restorations were removed and teeth preparations cleaned using a pumice-water slurry and low-speed prophy cup to remove salivary debris and any bacterial plaque in a gentle way to prevent gingival dilacerations (Figs 32a and 32b). The correct seating and contact points of the implant-supported crown and veneers were confirmed clinically and radiographically during the try-in.

The implant-supported crown was tightened with a final torque of 35 N (Figs 33a and 33b), and the screw-access hole of the abutment was sealed with PTFE tape and nanofilled composite resin (Filtek Supreme Ultra, 3M ESPE).

Ceramic Restoration Intaglio Preparation for Bonding

After the patient signed the form approving the shape and shade of the proposed treatment, the veneers were removed and prepared for the bonding procedures.

The intaglio surface of the veneers was cleaned with a steam jet to remove the try-in paste and other debris. All veneers were etched with 9% hydrofluoric acid (Porcelain Etch, Ultradent) for 90 seconds, rinsed under running water for 60 seconds, and then cleaned with 35% phosphoric acid (Ultra-Etch, Ultradent) for 60 seconds to remove crystalline precipitates that accumulate in the microporosities. The intaglio surfaces were dried with a stream of air, a universal primer for conditioning glass-ceramic restorations (Monobond Plus, Ivoclar Vivadent) was applied for 60 seconds, and any remaining excess primer was dispersed with a strong stream of air.[26]

Fig 34 Preparations etched with 35% phosphoric acid.

Fig 35 Chlorhexidine digluconate 2% solution applied to acid-etched dentin to inhibit the action of MMPs.

Fig 36 Universal adhesive system applied on etched enamel and dentin.

Figs 37a and 37b After complete evaporation of solvents, universal adhesives can be light cured without interfering with the seating of final restorations due to the minimal thickness of the adhesive layer. This technique is especially important to obtain superior sealing of exposed dentin surfaces and to enhance bond strength.

37a

37b

Veneer Bonding

The operative field was isolated with a rubber dam to inhibit any contamination by gingival fluid during the bonding procedures. A special clamp (W00) was used to retract both the rubber dam and the gingiva, exposing the subgingival cervical margin of the central incisor, and adjacent teeth were protected with PTFE tape and the tooth preparation microetched with 27-micron aluminum oxide for 10 seconds.

The bonding procedure must be performed according to the dental substrate. Resin-dentin bonding has become reliable with the introduction of hydrophilic adhesive systems. The low durability of resin-dentin bonding is related to the hydrolysis of unprotected collagen fibrils by host-derived enzymes in the incomplete resin-infiltrated hybrid layer.[27,28] Over time, collagen fibril degradation by metalloproteinases (MMPs)[27] and the cysteine-cathepsins[29] promote the hydrolytic breakdown of the bonded interface. One strategy to avoid the endogenous collagenolytic activity is the use of MMP inhibitors.[20] It has been demonstrated that when chlorhexidine digluconate is applied after the acid etching and prior to the adhesive system application, it helps to maintain the integrity of the hybrid layer over time.[30]

So, conscious of the limitation and challenges of long-term resin-dentin bonding, tooth preparation of the central incisor was etched with 35% phosphoric acid (Ultra-Etch, Ultradent) for 15 seconds in dentin and 30 seconds in enamel (Fig 34). After rinsing for 30 seconds, 2% chlorhexidine digluconate solution (Cavity Cleanser, Bisco) was applied to acid-etched dentin for 30 seconds and the excess was removed prior to the adhesive application (Fig 35). A universal multimode adhesive system (Adper Scotchbond Universal, 3M ESPE) was applied on the etched surface of the enamel and dentin and rubbed for 20 seconds (Fig 36). The adhesive was air dried for 15 seconds to completely evaporate the solvent[31] and individually light cured for 10 seconds (Figs 37a and 37b). When dentin is exposed on the tooth preparation, the adhesive system must be independently polymerized to ensure the formation of a dependable resin-dentin hybrid layer.[32] Moreover, the dentin bonding agent selected should create a thin adhesive film thickness; otherwise, it will interfere with the restoration adaptation onto the tooth preparation. Universal adhesive systems are therefore the only type of dental adhesives that can be polymerized safely before placement of restorations.

The restoration was adhesively bonded using resin cement (Variolink Veneer, Ivoclar Vivadent). After the veneer

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Fig 38 Overflow of resin cement removed from the margins using art brushes before final polymerization.

Fig 39 Final polymerization of the bonded veneer under air block.

Fig 40 No. 12 blade used to carefully remove minor excess of resin cement after polymerization.

Fig 41 Intraoral view of the final restorations.

was seated, the excess cement was removed using an art brush (Fig 38) and then light cured for 20 seconds. A layer of glycerin gel was applied on the bonded interface to prevent the oxygen-inhibited layer of resin cement before the final polymerization of each surface for 60 seconds (Fig 39). After rinsing off the glycerin gel, any remaining cement was removed from the margin using a surgical scalpel blade (Fig 40). All the other veneers were adhesively bonded following the same bonding protocol (Fig 41).

CONCLUSION

The success of anterior implant restoration in areas with an inadequate amount of bone is dependent on the multidisciplinary treatment planning. A broad understanding of the surgical and restorative procedures informs the selection of the best bone regeneration/augmentation technique and soft tissue manipulation during the implant placement surgery. Moreover, the use of a customized interim anatomical screw-retained restoration allows the soft tissues to gradually adapt to the pressure and mature to create an adequate emergence profile for the final restoration.

Bonding techniques associated with novel laboratory techniques have significantly evolved to allow maximum preservation of dental tissues. The long-term success of ultrathin bonded ceramic veneers depends on maximum enamel preservation, particularly at the gingival margin. However, in cases of tooth discoloration, when a large amount of dentin is exposed during the tooth preparation, the bonding protocol must be modified to ensure long-term success of the resin-dentin interface. The use of MMP inhibitor, dentin bonding system selection, complete evaporation of bonding agent solvent, and individual polymerization of the adhesive system before seating the restoration are crucial steps to ensure the longevity of the resin-dentin interface.

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