A novel approach to implant screw-retained restorations: Adhesive combination between zirconia frameworks and monolithic lithium disilicate

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Abstract

The use of zirconia is an esthetic alternative to metal for implant-supported frameworks, and it has increased primarily for its high biocompatibility, low bacterial surface adhesion, high flexural strength and high mechanical features. The zirconia frameworks in fixed prosthetic restorations that are supported by implants is commonly covered with hand-layered overlay porcelain. This technical procedure is highly esthetic but it can cause some complications, such as porcelain fractures.

The purpose of this article is to introduce an innovative approach to create an esthetic fixed ceramic implant restoration to minimize and facilitate the repair of the mechanical complications, by combining the adhesive-cementation of lithium disilicate full coverage restorations on implant screw-retained zirconia frameworks.

(Int J Esthet Dent 2014;9:490–505)

Introduction

Advances in dentistry have given rise to an increased use of implant therapy in the prosthetic reconstruction of edentulous or partially edentulous patients. Dental implants serve as analogs of natural teeth, but they are osseointegrated to bone. The absence of a periodontal ligament (PDL) is the key feature that distinguishes the peri-implant supporting apparatus from the periodontium.[1,2] The PDL acts as a cushion around the teeth and it is composed of collagen fiber groups oriented in multiple directions. Occlusal forces are applied to teeth from multiple directions, and the PDL provides a shock-absorbing effect by stretching and adapting to these forces.[2,3] Furthermore, the PDL has neurophysiologic receptors that can detect changes in the occlusal forces encountered. Because implants are osseointegrated, there is almost no space between implants and the surrounding bone; as such, the movement of implants under loading is limited.[2] Therefore, this changes the patterns of force distribution around implants.[3,4] Implants have a significantly higher detection threshold of minimal pressure, compared to the natural dentition.[5,6] Numerous studies have demonstrated high implant survival rates, but complications continue to be reported.[2,7-10] A previous systematic review specified two categories of complications that occur in implant dentistry: biological and technical.[11] Biological complications refer to disturbances in implant function that affect the supporting peri-implant tissues.

These include early and late implant failures and adverse reactions in the peri-implant hard and soft tissues. 'Technical complication' is a collective term to describe mechanical damage of the implant, implant components, and suprastructures. Prosthetic complication after the definitive prosthesis is placed may or may not lead to implant loss but can result in an increased need for repair and maintenance.

Few studies have attempted to assess the costs associated with implant-supported fixed complete dental prostheses and maintenance.[12,13] The most common biomechanical complications related to fixed prostheses supported by implants with metal frameworks are resin veneer and porcelain fracture.[14,15] It was found that implant-supported fixed partial dentures (FPDs) had a significantly higher 5-year risk of porcelain fracture or chipping compared with tooth-supported FPDs (8.8% versus 2.9% respectively) and that as many as 38.7% of all implant-supported fixed dental prostheses (FDPs) for partially edentulous patients had some type of adverse event during an observation period of at least 5 years.[16] With the primary focus of improving accuracy, decreasing cost, and simplifying manufacturing procedures, dental implant research has invested in the development of computer-assisted design/computer-assisted manufacturing (CAD/CAM) technology. The advantage of industrialized manufacturing of zirconia frameworks from homogenous blocks using CAD/CAM technology and subtractive prototyping has improved accuracy and cost effectiveness.[17]

Zirconia has gained increasing popularity in contemporary dentistry due to its high biocompatibility,[18] low bacterial surface adhesion,[19] high flexural strength, toughness due to a transformation toughening mechanism,[20] and esthetic properties.[17,21] These properties have led to the introduction of zirconia-based restorations as alternatives to the traditional porcelain fused to metal (PFM) restorations. It is currently being used for the fabrication of implant abutments and all ceramic copings, multiple units, and complete frameworks for both fixed prosthodontics and implant dentistry.[22-26] Clinical data with up to 5-year clinical follow-up confirmed the high stability of zirconia as a framework material for tooth-supported fixed dental or implant prostheses and crowns; however, the ceramic chipping rate of the veneering porcelain was higher than in PFM restorations.[24-26] As a rule, the last step in the fabrication of all-ceramic restorations involves veneering porcelain on the zirconia frame. Only one randomized controlled clinical trial[27] reported comparative preliminary data on the survival and success rates of PFM and porcelain fused to zirconia (PFZ) tooth or implant-supported three-to five-unit FDPs after 3 years in function. The study reported no differences in framework survival, whereas the PFZ success rate was lower due to an increased risk of the porcelain veneer chipping.[27] Consequently, the expanding use of zirconia frameworks is faced with a new challenge: chip-off fractures of veneering porcelains.[28] The mechanical factors that influence chip-off fractures relating to the thickness and toughness of veneering porcelain and restoration geometry include: lack of proper veneering porcelain support; inadequate framework design; location of contact areas; and the bond strength of veneering porcelain zirconia.[29-31] Notably, regarding the bond strength factor, Guess et al reported that the bond strength of porcelain to zirconia was lower than that of porcelain to metal.[30] In order to achieve a highly esthetic ceramic restoration, simplify fabrication procedures, improve predictability of maintaining prosthetic implant reconstructions, and facilitate managing post-treatment technical complications, the authors show a novel fabrication method that considers the combination of lithium disilicate restorations with zirconia CAD/CAM frameworks (Figs 1 to 3).

Among many options, in the late 1990s, lithium disilicate glass-ceramic was introduced to dentistry as a framework material. Its flexural strength ranges between 300 and 400 MPa and its fracture toughness between 2.8 and 3.5 MPa/m½.[32] Lithium disilicate glass-ceramics are typically fabricated through

Fig 1 Anterior rehabilitation on implants and a natural abutment. Implants are placed in the position of lateral incisors and a zirconia framework was designed to retain four cemented lithium disilicate single crowns. Since the implant framework screw access holes were located on the palatal aspect of the crowns, the implant-supported fixed partial denture restoration was screw-retained.

Fig 2 Clinical try-in of the zirconia framework. The design allows a vertical path of insertion of the full coverage lithium disilicate single restorations.

Fig 3 Final result after 3 years of function. The rehabilitation was completed with six lithium disilicate single crowns: two adhesively cemented intraorally on the natural canines and four adhesively cemented extraorally on the implant zirconia framework. Subsequently, this framework was screw-retained onto the implants located in the lateral incisor position.

a combination of the lost-wax and heat-pressed techniques or milled with (CAD/CAM) systems and used for the same indications.[33]

Because of its high strength, this material can be used for the fabrication of monolithic crowns chairside or in the laboratory with subsequent staining and characterization. This can potentially reduce the incidence of chip-off fractures, and furthermore, thanks to etch techniques, can facilitate the intraoral repair of veneering possible porcelain fractures.[23-36]

Clinical and technical procedures

Step 1: Framework design

Typically, zirconia or metal frameworks were characterized by an *anatomical design* in order to support the precise uniform thicknesses of veneering porcelain (Fig 4).[33,34,37] In fact, when the core properly supports the veneering ceramic, the overall performance of the zirconia restoration improves and results in a lower chipping rate.[37-40]

With the adhesive-cementation technique of lithium disilicate ceramic crowns, the zirconia framework design does not require the same features as the layered-porcelain technique. This is because lithium disilicate is stronger and tougher than conventional veneering porcelain,[35] therefore it does not require support from the framework design[35,41] and, moreover, it can be produced with a monolithic full-contour technique (Fig 5).

The zirconia framework has a prosthetic design, effectively augmenting the structural toughness and retention of the lithium disilicate full coverage restorations by allowing the restoration to have a larger thickness of ceramic material, as compared to the thickness associated with the layered porcelain technique.

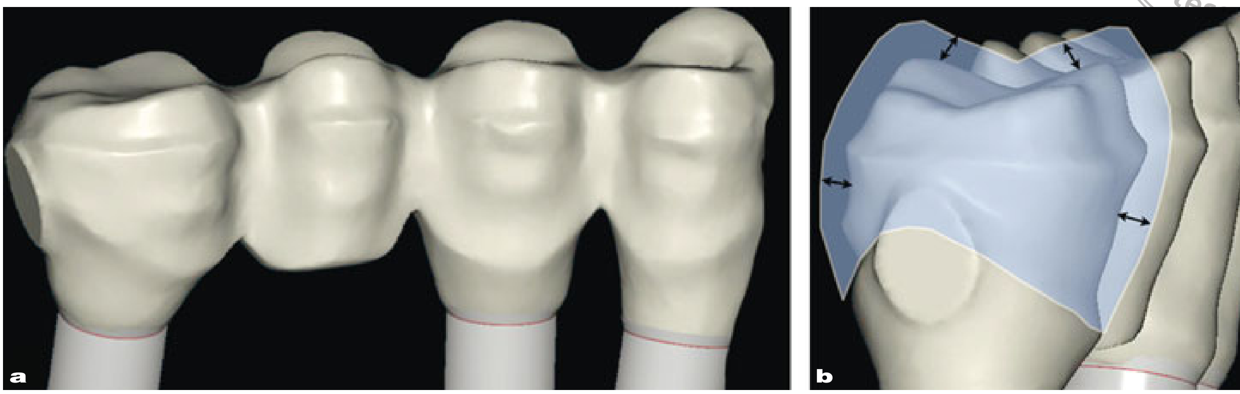

Fig 4 Framework design for layered porcelain technique. Layered porcelain needs frame-protrusion in order to be supported. A maximum and uniform thickness of 2 mm is recommended in order to avoid porcelain fractures.

Fig 5 Framework design for the adhesive-cementation technique. Lithium disilicate restorations do not require support from the zirconia framework and can also have dimensions with a larger thickness. The zirconia framework has a conventional tooth-preparation type of prosthetic design with no undercuts, therefore creating a vertical path of insertion for cementation of the individual crowns.

The design of the framework for the adhesive cementation of restorations does not need to be extended, as it does with the layered porcelain technique, in order to support the ceramic. The design also does not provide undercuts (Figs 5 and 6). Therefore, the framework can be designed with a vertical path of insertion and cementation of the full coverage restorations. A similar framework design has been described[42] in order to solve the severe angulation of dental implants when a fixed screw-retained-titanium dental prosthesis is planned.

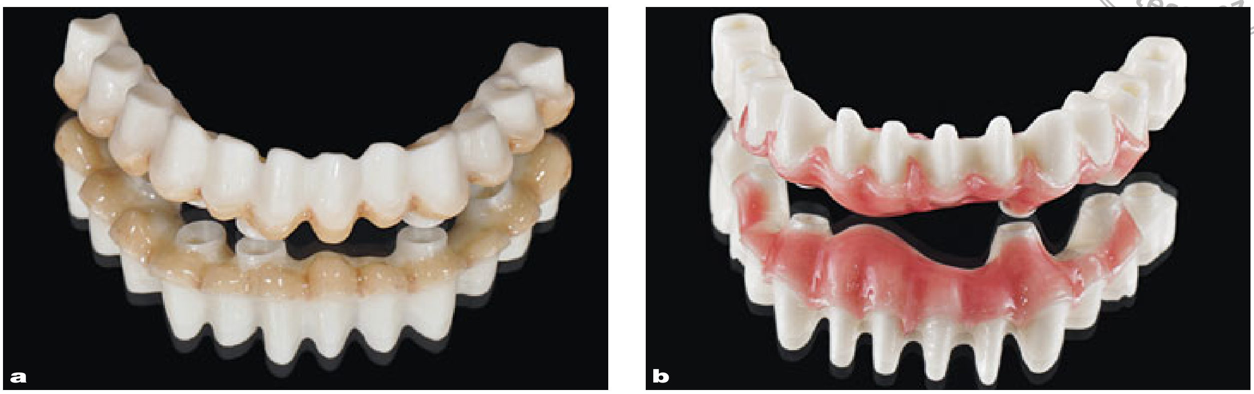

Fig 6 Examples of framework design for adhesive technique. **(a)** Complete lower rehabilitation with dental implant-supported prosthesis. Due to the limited vertical height, the framework was designed with the artificial root to be fabricated in zirconia in order to strengthen the framework. **(b)** Complete lower rehabilitation with hybrid implant-supported prosthesis. In all these cases, vertical height of the framework abutment preparation is adequate; pink porcelain was layered on the framework in order to recreate soft tissues.

Step 2: Fabrication of lithium disilicate restorations

Lithium disilicate restorations can be fabricated using a press technique or CAD/CAM technology[43-45] and both manufacturing processes can result in restorations with appropriate marginal fit and placement.[44,45] The occlusal reconstruction can either be designed with single non-splinted monolithic crowns or multiple monolithic splinted crowns, depending upon the position of the screw access hole of the framework, the interocclusal space as it relates to the vertical height of the framework abutment preparations for adequate retention, and the esthetic preferences of the patient. It could be advantageous to simplify the technical procedures associated with designing the contours, placement and cementation of the full coverage restorations by fabricating the restorations in splinted posterior and splinted anterior segments.

The monolithic full contour restoration can create an idealized occlusal form and function, while also reducing the risk of fracture for the veneering porcelain. The esthetic desires can be achieved by using high translucency ingots and a staining approach in the posterior seg-

Fig 7 Complete implant-supported rehabilitation in the maxilla and mandible. Zirconia frameworks were combined with high translucency (HT) lithium disilicate monolithic restorations. A satisfactory natural appearance was obtained only with a staining approach.

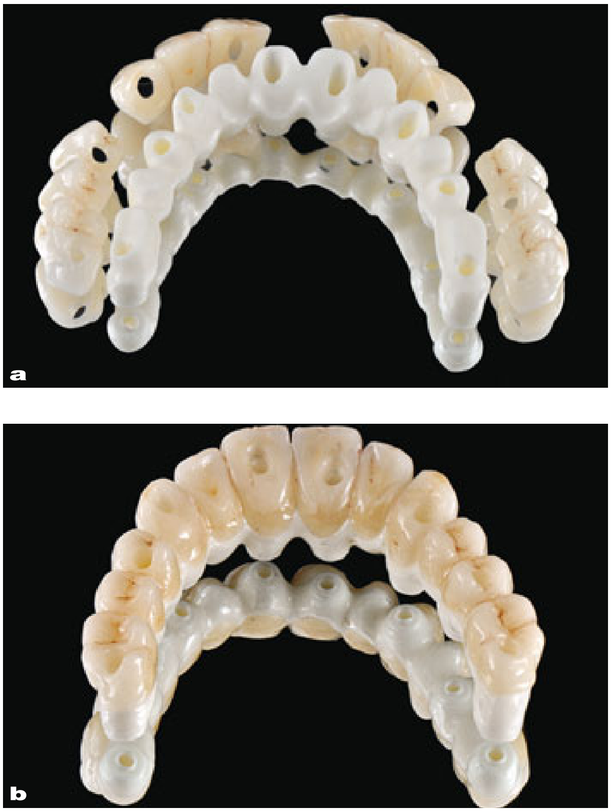

Fig 8 Full arch in the maxilla. **(a)** The frame was combined with four pressed lithium disilicate three-unit bridges. The restorations are pressed with the screw holes in proximity of implants. **(b)** Final result after the cementation of the four bridges.

Fig 9 Full arch in the maxilla. **(a)** The frame was combined with 28 CAD/CAM lithium disilicate single crowns. The restorations are produced in lithium metasilicate (blue material) and then the screw holes are created with calibrated burns, in fact in this phase the material is easy to work with. Subsequently after a crystallization process, the restorations will obtain lithium disilicate. **(b)** Definitive restoration after the cementation of the single restorations with resin cement.

ments, and layering porcelain or staining in the anterior segments (Fig 7).

The salient point to note is that the restorations to be placed above the implants have to be devised with palatal or occlusal screw-hole access, in order to perform extraoral cementation on the frameworks to obtain screw-retained definitive rehabilitations. In such cases, it is of paramount importance that the position and axis orientation of implants be very carefully planned presurgically, using appropriate radiographs and mounted study models (Figs 8 and 9).

Step 3: Adhesive cementation of lithium disilicate restorations to zirconia frameworks

The feasibility of this technique was assessed by investigating the bonding strength of machinable ceramic to zir-

Fig 10 Framework design for single crowns. On the palatal aspect, a horizontal coulisse was carried out in order to facilitate the cementation in the exact position.

conia.[28] The adhesion of resin cements to zirconia improves through the use of primers and surface modification treatments, developed specifically for zirconia resin bonding.[46-48] Takeuchi et al reported that a maximum bonding strength of 49.4 MPa was achieved between resin cement and zirconia.[28-47] Lithium disilicate restorations require adhesive techniques using resin cements strictly in accordance with manufacturers' instructions (Es. RelyX Unicem, 3M ESPE; Multilink Automix, Ivoclar Vivadent; Variolink II, Ivoclar Vivadent). The restorations must be etched for 20 s with 4.5% hydrofluoric acid (Porcelain Etch, Ultradent), then washed with water and dried. A silane agent (Monobond S, Ivoclar Vivadent; Ceramic Primer, 3M ESPE) must be applied and blown dry on the restorations. The zirconia surface was treated with silica coating with 30 μm silica-modified alumina (Al_2O_3) particles (CoJet Sand) and zirconia primers.[49-53] To facilitate the correct positioning of the restoration on the zirconia frame, in particular in the case of single crowns, it is valuable to carry out specific abutment framework designs (eg, vertical and horizontal coulisses) and to verify the right position by a silicone occlusal index (Fig 10).

Teflon, cotton or wax, can be used to occlude the screw holes during luting procedures. Cementation procedures must include cement excess removal with a scaler after a preliminary light curing, then light polymerization is applied (Bluephase LED, Ivoclar-Vivadent) for 30 s from each side after the positioning of glycerin gel on the margins. It was recommended to divide the cementation phase in more steps: two or three restorations maximum at a time. The margins have to be finished with a microblade in order to remove definitively residual cement. It is recommended to cement the restorations on the screw holes at the end and with single crown restorations; in this way it is possible to perfectly control the cleaning of the screw hole from excess cement in the case of extraoral cementation. In the rare case of intraoral cementation, for an inadequate axis implant orientation the screw hole would be on the vestibular wall.[42] Moreover, an important parameter is the abutments' height and adhesion surface. In fact, in the case of short and small abutments, and therefore with low retention, the possibility to produce connected restorations reduces the risk of decementation.

Discussion

The frequency of chip-off fractures is higher in zirconia restorations than in conventional PFM restorations.[30] In conventional PFM restorations, the chip-off fracture rate after 10 to 15 years of clinical service ranged between 2.7 and 5.5%.[54,55] In zirconia restorations, the chip-off fracture rate was 15% after 24 months of clinical service[56] and 25% after 31 months.[57] In fact, the main clinical concern reported in the literature regarding Y-TZP used as a framework material is a higher incidence of veneering porcelain chip-off fracture rates[17,31,58] ranging from 15% to 54% over a 3- to 5-year period[58,59] versus 2.9% to 8.8% ceramic fracture rates observed in conventional tooth- and implant-supported metal-ceramic restorations over 5 years.[16] Recently, a retrospective clinical study of layered cross-arch zirconia bridges[37] showed excellent results after an observation period ranging between 3 and 5 years, thanks to an accurate fabrication protocol: chip-off fracture rates of the porcelain veneer occurred in three of the total 26 full-arch restoration, scoring a cumulative prosthetic success rate of 89%; from the dental unit perspective, five of 348 dental units experienced veneering material chipping, yielding a cumulative prosthetic success rate of 99% at the unit level.

However, with recent developments in CAD/CAM technologies and with the introduction of new ceramic materials, the possibility of milling full-contour ceramic restorations without veneering porcelain has gained increasing importance and popularity in order to simplify technical and prosthetic procedures.[60,61] Moreover, it leads to the aim of avoiding ceramic chipping and to reduce wear of ceramics and antagonists, both phenomena that cast a shadow on the high esthetic potential of veneering ceramics.[62-64] A novel method was developed to fabricate implant-supported screw-retained rehabilitations, which are comprised of monolithic lithium disilicate all-ceramic restorations bonded to CAD/CAM-fabricated zirconia frameworks using resin cement. The purpose was to introduce an alternative to the hand-layered veneered zirconia in order to preserve all advantages of zirconia, in terms of esthetics, biocompatibility, plaque adhesion, resistance, and meanwhile simplifying technical and prosthetic procedures and reducing the potential risk of veneering porcelain chip-off fractures.[26,31]

Particularly regarding the bond strength factor, Guess et al reported that the share bond strength of porcelain to metal was 27.6 MPa, while that of porcelain to zirconia was 9.4 to 11.5 MPa.[30] Rocha et al reported that in an incomplete bond between the veneer and the zirconia framework, the stress in the ceramic veneer increased and induced veneer failure.[65] Therefore, an improved bonding system stronger than that afforded by the conventional fusing technique is needed.[65] The use of monolithic lithium disilicate restorations in anterior and posterior segments on implant-supported restorations was investigated in several *in vitro* and clinical studies; the potential reliability of this approach is due to the adequate flexural strength of lithium disilicate and the possibility of using it in full contour,[35,60,66] without any layered material. In a prospective clinical study, Kern et al explained that FDPs made from monolithic lithium disilicate ceramic showed 5- and 10-years' survival and success rates that were similar to those of conventional metal-ceramic FDPs.[67]

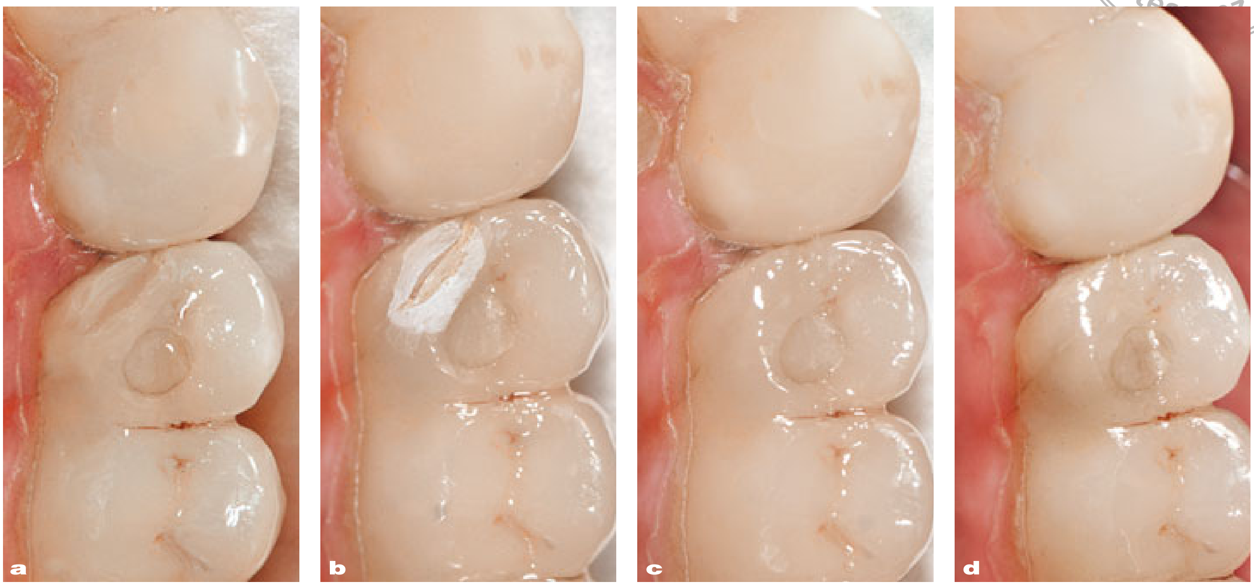

Fig 11 Chipping treatment with this novel approach. **(a)** After 4 years of function, the hygienist shows the complication. Adequate remaining surfaces of lithium disilicate allow for the etching technique to be effective on all the exposed area. **(b)** The surface after etching with 4.5% hydrofluoric acid for 20 s. **(c)** The ceramic surface was treated with silane and bonding, and subsequently the direct restoration was finalized with composite. The image shows the cavity after the polishing. **(d)** At 3-years follow-up, the direct restoration is still well-maintained.

The key element of this technique relates to the union between the lithium disilicate restorations and the zirconia framework through resin cement. The minimum debonding/crack-initiation strength set by the ISO 9693 standard for metal-ceramic bond is 25 MPa (ISO 9693, 1999).[68] The shear bond strength of porcelain fused to metal is approximately 27.5 MPa.[30] Clinical studies have assessed the bonding strength between zirconia and lithium disilicate to be from 25 MPa to 40 Mpa, depending on the resin cement used.[28,47] Therefore, this data suggests the reliability of this approach of adhesive cementation of lithium disilicate restorations to zirconia frameworks. A recent retrospective analysis took into consideration 18 rehabilitation (236 dental units) on 16 patients; 1 out of these 18 rehabilitations (1 out 236 dental units) showed a chip-off fracture, scoring a cumulative prosthetic success rate of 100%.[69] These reports suggested that veneer chippings stemming from low core-veneer bond strengths might be solved by adhering monolithic lithium disilicate to zirconia frameworks using resin cement. The novel approach described can be applied in clinical situations from the single tooth to the complete arch rehabilitation.

In case of chipping failure, it can also be easily repaired using a bonding approach. In fact, by maintaining a lithium disilicate thickness of at least 2 to 3 mm around the framework in case of fracture, there are adequate etchable surfaces and thicknesses where a reliable direct composite resin can be adhesively bonded (Fig 11).[36,70,71]

Fig 12 Treatment of grave fracture after a car crash. **(a)** Grave factures on both maxillary central incisors. A direct restoration in composite was performed immediately in order to recreate temporarily esthetics and function. The image shows the fracture after etching. **(b)** Result obtained with composite. **(c)** After 3 months, the old fractured crowns are removed. **(d)** Zirconia framework abutments are exposed, traditional impression with silicone is taken, and a acrylic temporary restoration is placed. **(e)** New crowns on the model. **(f)** Crowns after the intraoral cementation. The framework design allowed the precise reproduction of the rehabilitation. All these procedures could also be performed in the laboratory as the restoration is screw retained; but it is easier to do all this in the mouth by using a traditional prosthetic approach with natural abutments.

In situations concerning major chippings that require a complete tooth replacement, the reparation can be performed easily thanks to the framework design, which allows a vertical insertion of the restoration.[28,42] This is not possible in the case of layered frameworks where the anatomical design and the ceramic pillars establish undercuts, which impede the correct placement of a new restoration. All procedures can be performed easily in the mouth with the prosthetic approach used in natural abutments (Fig 12). In fact, the removal of this rehabilitation needs a lot of time to accurately remove the resin from the screw holes and therefore it is only recommended to do this in the case of biological complications.

Conclusion

The illustrated novel fabrication method for all-ceramic restorations could be a promising alternative to the conventional porcelain layering technique, whereby veneering etchable glass-ceramics would be bonded to CAD/CAM zirconia frameworks with resin cement. The advantages are:

- to idealize the esthetic outcome of the prosthetic treatment
- to reduce the incidence of chip-off fracture rate
- to facilitate the retreatment of unforeseen possible ceramic fractures.

Long-term studies using this novel approach are needed to further understand the potential of this innovative technique.

Acknowledgments

The authors greatly appreciate all the help given by dental laboratory Kronos (Perugia, Italy), Paolo Rossi (Cattolica, Italy) and Vitaplus (Cattolica, Italy) who fabricated the restorations, and oral surgeons Dr G Ban (Cattolica, Italy) and Dr E Maschera (Milan, Italy).

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