Rationalization of Esthetic Restorative Dentistry Based on Biomimetics

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ABSTRACT: The exponential progressivism that characterizes the current decade often comes with substantial financial implications. Dental care is not spared by this phenomenon. However, new generations of concepts emerging from biomimetics provide the operator with the ability to restore the biomechanical, structural, and esthetic integrity of teeth. The development of adhesion and the evolution of porcelain veneers constitute striking examples of this nascent process. Indications for bonding porcelain are extending to more perilous situations (crown-fractured incisors, nonvital teeth), resulting in considerable improvements, comprising both the medical-biologic aspect (economy of sound tissues and maintenance of tooth vitality) and the socioeconomical context (decrease of costs compared to traditional and more invasive prosthetic treatments).

CLINICAL SIGNIFICANCE: In the bonded porcelain veneer and its extensions, restorative dentistry has found new solutions for the anterior segment that balance the need for functional and esthetic reconstruction. The optimal stiffness of porcelain in thin section, the ideal surface characteristics, and the biomechanical continuum achieved through high performance bonding mean the crown of the tooth as a whole can support incisal or masticatory function. By the same token, the conduction of optical effects from within the tooth combined with the ideal surface features of the porcelain veneer make this restorative approach the ultimate in esthetic satisfaction, for both the practitioner and the patient.

"Knowledge is dropping from the tongue of the wise..." (The Bible in Basic English, Proverbs 15:2)

In the current decade, the most exciting developments in dentistry are emerging. Oral implantology, guided tissue regeneration, and adhesive restorative dentistry constitute strategic growth areas in both research and clinical practice. However, the abundance of developments in dental materials and technology also has generated a plethora of dental products in the marketplace. The practitioner and the dental technician alike are faced with difficult choices, owing to the growing number of treatment modalities. Further, the expansion mode of technology does not always lead to simplification and decrease of treatment costs. Both prudence and wisdom need to be combined with knowledge and progress when it comes to improving the patients' welfare.

In this perplexing context, no one will contest the need for less costly, more reasonable, satisfactory, and rationalized substitutes for current treatments. The answer might come

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from a newly emerging interdisciplinary biomaterial science designated "biomimetics."[1] This concept of medical research involves the investigation of both structures and physical functions of biologic "composites" and the designing of new and improved substitutes. In dental medicine, the term biomimetics is a useful, increasingly applicable word. The primary meaning refers to material processing in a manner similar to the natural process within the oral cavity, such as the calcification of a soft tissue precursor. The secondary meaning of biomimetics refers to the mimicking or recovery of the biomechanics of the original tooth by the restoration. This of course is the goal of restorative dentistry.

Several research disciplines in dental medicine have evolved with the prospect to mimic oral structures. However, this still nascent discipline is applied mostly at a molecular level, aiming to enhance wound healing, repair, and regeneration of soft and hard tissues.[2,3] The benefit of biomimetics, when extended to a macrostructural level, is that it can trigger innovative principles in restorative dentistry. Restoring or mimicking the biomechanical, structural, and esthetic integrity of teeth constitutes the driving force of this process. The object of this report, then, is to propose modern criteria for the rationalization of esthetic restorative dentistry based on biomimetics.

BIOMIMETICS AND PORCELAIN VENEERS: SETTING THE STANDARDS FOR ANTERIOR TEETH

Enamel–Dentin Complex: A Reference in Arrangement and Material Properties

Mimicking in science involves designing to reproduce and copy a model, that is, a reference. For the restorative dentist, the unquestionable reference is the intact natural tooth. Biomimetics therefore starts with the understanding of hard tissue arrangement and related stress distribution. Enamel and dentin form a complex structure that provides a tooth with unique characteristics[4]: on the one hand, the hardness of enamel protects the soft underlying dentin; on the other

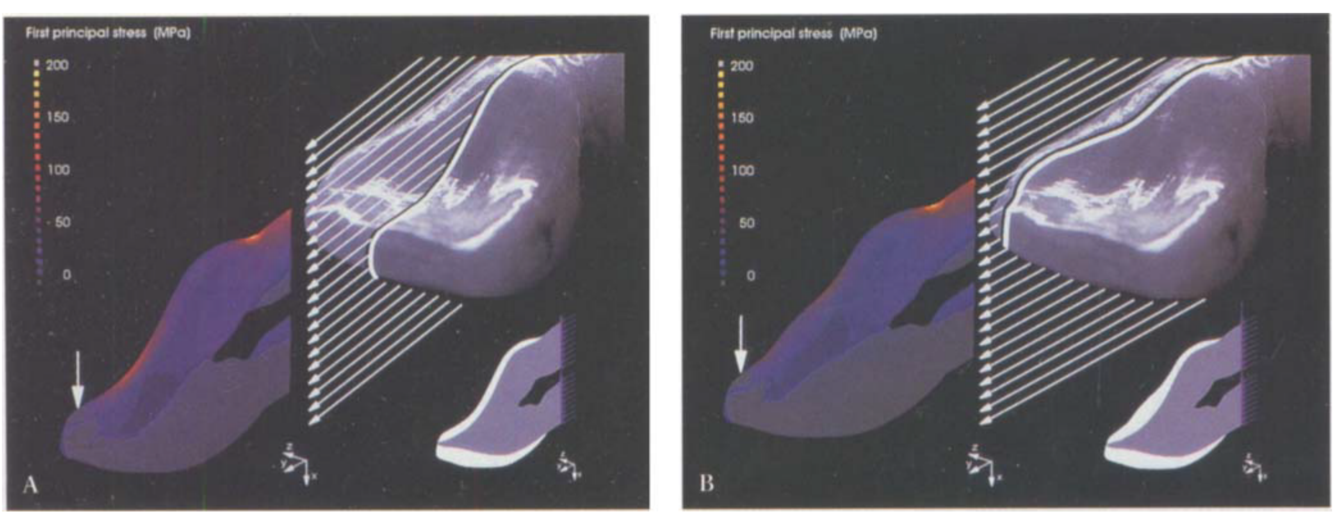

*Figure 1. Palatal view of a central incisor and first principal stress distribution. The palatal surface displays a contrasting anatomy. Strong proximal crests extend from the incisal edge to the tubercule, delineating a deep concavity with thin enamel. A 2-D finite element (FE) model of a buccolingual cross-section was used to predict the effect of a 50-N load on the incisal edge (*white arrow*). A, Tensile stress concentration in the concavity. The facial half of the tooth is mainly subjected to compressive stresses (*gray surface*). B, The same FE model modified to simulate the convex geometry and thickness of enamel at the level of the proximal crest; the resulting stresses are significantly decreased.*

Figure 2. Enamel microcracks. Numerous composite restorations compensated for incisal tooth wear. On the central incisors, thin enamel was characterized by the presence of multiple vertical cracks. Porcelain veneers were planned to establish stability of function and esthetics (see Figure 5).

hand, the crack-arresting effect of dentin and of the thick collagen fibers at the dentin–enamel junction compensate for the inherently brittle nature of enamel.[5] The structural and physical interrelation between an extremely hard tissue and a more pliable softer tissue provides the natural tooth with its unique ability to withstand masticatory and thermal loads during a lifetime. Although multiple enamel cracks are typically encountered in aged teeth, these senile changes seldom propagate through the entire enamel–dentin complex of the tooth.

Anatomic Features of Anterior Dentition: Enamel as a "Regulator" of Stresses

Anatomically, the anterior segment of the dental arch is characterized by the process of "incisivization." Thus the occlusal table is gradually replaced by an incisal edge that has the obvious function of cutting. The labial aspect of the incisors is mainly convex, whereas the palatal part of the tooth displays a deep concavity extending axially between the dental cingulum and the incisal edge and laterally between the two strong proximal ridges (Figure 1). Because of this specific shape, the incisal edge assumes a blade-like configuration, determining the cutting efficiency of the tooth. Owing to the arrangement and position of the anterior dentition, the mechanical loads act mainly in the buccopalatal plane of each tooth. Mesiodistal loads are restrained by proximal contact areas. Anterior esthetic techniques often involve labial and interproximal reduction of enamel, which makes the tooth crown more deformable.[6,7] The resistance of the crown to deformation in the anteroposterior direction is a major contributor to the fracture strength of the tooth. The effect of varying enamel reductions is quantitatively determined by the crown flexure, which can be measured under simulated conditions by bonded strain gauges. It appears that the palatal concavity, which provides the incisor with its sharp incisal edge and cutting ability, is an area of stress concentration (see Figure 1, A).[8] This shortcoming can be compensated for by specific areas featuring convex and thick enamel, such as the cingulum and the marginal ridges (see Figure 1, B). It can be presumed that moderate stress concentrations would occur on the totally convex palatal surfaces, such as that found on canines. Canines also present curvilinear facial surfaces that may better withstand compressive forces. The effect of

Figure 3. Generalized enamel dysplasia. A, *Upper teeth previously were treated using classic PFM crowns. Lower teeth still exhibited the original surface defects, the situation being complicated by marked crowding.* B, *After a complex preprosthetic phase, including the extraction of a mandibular incisor, followed by orthodontic realignment, seven veneers were placed on the remaining mandibular incisors and first premolars along with six maxillary anterior crowns.*

shape (convex versus concave) and composition (enamel–dentin distribution) are universal and do not depend on the exact load direction or magnitude. Thus, the way stresses are distributed in a tooth structure is orchestrated by the anatomy and geometry of the enamel shell. The latter may be conceptualized as a regulator in the balance of stresses. When enamel is worn down or removed from the facial surface, its replacement should be carried out using materials with similar properties, to restore the original biomechanical behavior of the tooth—the biomimetic principle. Aged teeth with thin enamel are expected to display higher surface stresses.[8] The presence of numerous enamel microcracks stands as a confirmation of this fact (Figure 2). When the original enamel thickness is restored, using porcelain as a substitute, the tooth recovers its original structural, optical, and biomechanical properties. Morphologic defects, as in the case of enamel dysplasia, generate both mechanical and esthetic problems (Figure 3, A). If only localized, the defects can be treated using composite resins; however, generalized enamel dysplasia is best treated with ceramic restorations (Figure 3, B).

Risks of Biomechanical Mismatch: Resilience as a Possible Indicator

Owing to the improvement of adhesive procedures and the development of restorative materials, the biomechanical behavior of the enamel–dentin complex can be partially recovered. In this context, it seems reasonable to conclude that new restorative approaches should not necessarily aim to create a restoration with the strongest materials but rather a restoration that is compatible with the mechanical and biologic properties of underlying dental tissues. The dramatic consequences of biomechanical mismatch (lack of biomimetics) between tooth and restoration has been documented in the literature. A simulated impact study showed the problematic root fracture pattern generated with stiff restorations (gold crowns, porcelain-fused-to-metal [PFM] crowns), whereas teeth veneered with bonded porcelain performed similarly to intact teeth.[9] Other authors have shown the excessive ultimate strength of teeth bonded with porcelain veneers when it comes to the restoration of incisal length.[10,11] A key element to understanding these contrasting behaviors is the concept of tooth compliance or flexibility. The latter constitutes an essential quality in any structure, otherwise it would be unable to absorb the energy of a blow. In other words, a compliant restoration will cushion a sudden blow by bending elastically under the load. Up to a point, the more resilient a structure is the better.[12] Clinically, the most compliant structure is often constituted by intact natural teeth, which can be considered a reference. Stokes and Hood showed that in an impact situation, the intact tooth absorbed the highest energy of fracture, compared to teeth restored with veneers or different types of crowns.[9] The respect of the aforementioned parameters goes well beyond pure mechanical considerations. In vivo, mechanical events are intimately balanced with the biologic integrity of the tooth. The price of a blow can be paid in the form of either a mechanical or a biologic failure (pulpal involvement). A crown fracture might be a preferable event if one considers that the energy absorbed during fracture can prevent further biologic damage or root injury (Figure 4).

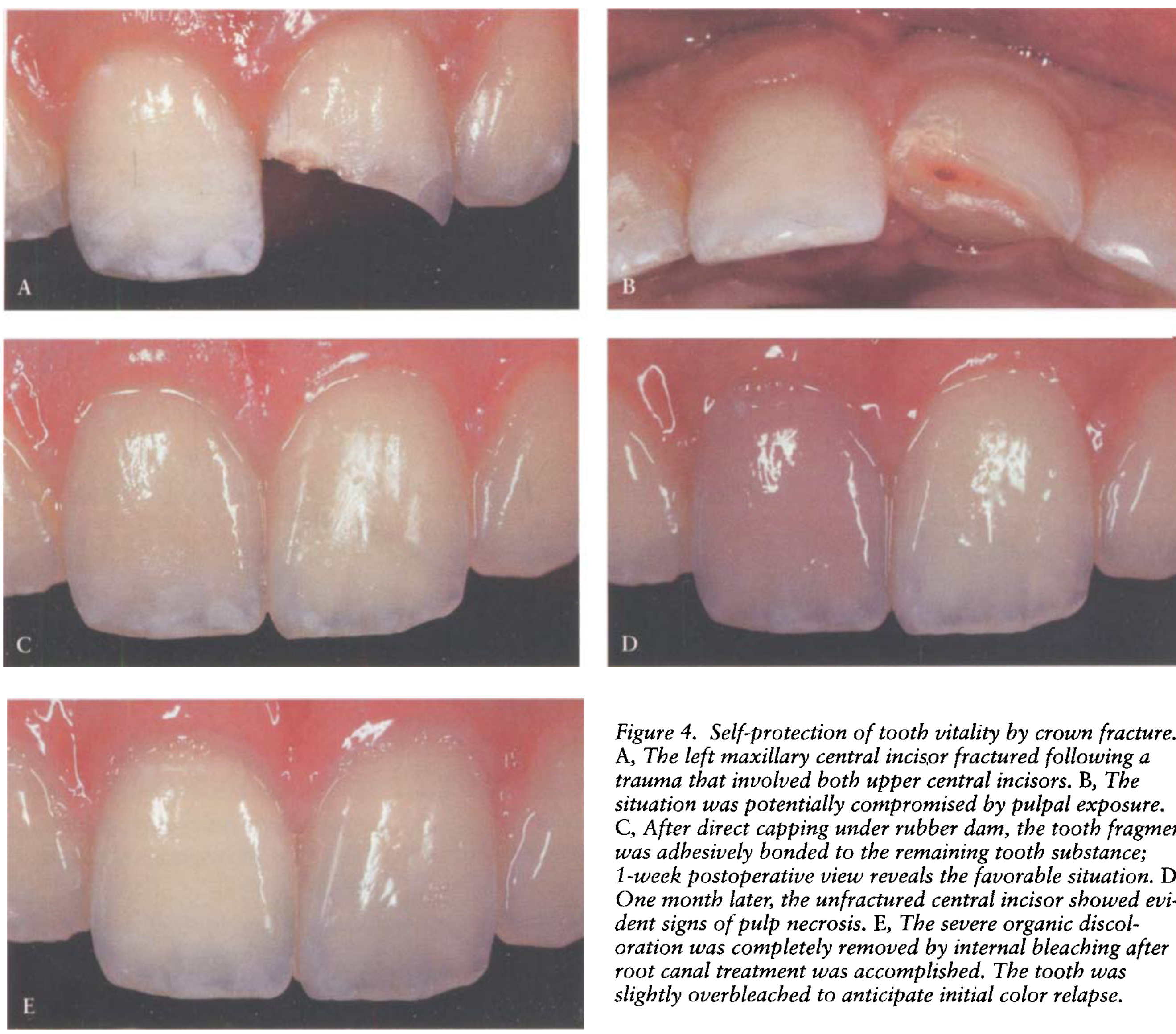

Figure 4. Self-protection of tooth vitality by crown fracture. A, *The left maxillary central incisor fractured following a trauma that involved both upper central incisors.* B, *The situation was potentially compromised by pulpal exposure.* C, *After direct capping under rubber dam, the tooth fragment was adhesively bonded to the remaining tooth substance; 1-week postoperative view reveals the favorable situation.* D, *One month later, the unfractured central incisor showed evident signs of pulp necrosis.* E, *The severe organic discoloration was completely removed by internal bleaching after root canal treatment was accomplished. The tooth was slightly overbleached to anticipate initial color relapse.*

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Porcelain Veneers: An Essential Component to Mimic Anterior Tooth Response
Among modern dental materials, ceramics best feature the physico-mechanical characteristics of enamel in terms of elastic modulus, fracture strength, hardness, and thermal expansion. Stiffness and hardness of dentin are more likely to be simulated by some composite resin materials. Because of their elastic modulus, composites alone are not able to restore the loss of stiffness following tooth preparation and the related extensive loss of enamel.[7] Thus, porcelain veneers can be considered to be an essential component in restorative dentistry. Similarities are expected in the stress pattern and compliance of intact teeth and teeth for which the restoration reproduces the geometry and arrangement of enamel and dentin using ceramic and composite as enamel and dentin substitutes, respectively. But the great potential of porcelain veneers is not limited to the respect of scientific and objective parameters related to biology and mechanics. Ceramic laminates provide the clinician with a powerful modality with regard to esthetics. Even in those cases in which it is not the primary objective, oral esthetics still requires special consideration. Modifications of form, position, and color of anterior teeth generate significant effects on the smile, which in turn contributes to enhance the personality and social life of the patient (Figure 5).

BONDING: THE CORNERSTONE OF STRUCTURAL INTEGRITY

First Goal: To Preserve Enamel through Diagnostic Wax-Ups
Enamel is a specialized tissue. The fact that it is etchable makes it exceedingly valuable to the clinician. The long-term success of porcelain veneers bonded to enamel stands as a witness for the clinical value of enamel.[13-16] Tooth preparation techniques for laminate, have not always promoted this fact. Reduction burs with calibrated diamond rings were proposed to cut enamel with depth control related to the preexisting tooth surface. When the initial enamel is already thin, reduction made using such depth cuts may lead to major dentin exposures. In cases of thin initial enamel, the restoration goal should be to restore the original volume of the tooth. Therefore, a diagnostic wax-up restoring the original volume of the tooth should be used as a reference for tooth reduction, using silicon matrices as a guide in vivo (see Figure 5, D and E). This simple procedure allows the saving of a significant amount of sound tissue, not only enamel but also the critical dentin–enamel junction (DEJ).

Dentin–Enamel Junction: A Reference for Dentin Bonding
The structural integrity of the intact tooth can be explained in part by the structure–property relations at the DEJ.[5] Enamel and dentin considered alone do not feature impressive mechanical properties; however, when assembled at the DEJ, they constitute a unique structure. Full-thickness enamel cracks almost never propagate through the DEJ or along the plane of the DEJ. This sets the reference for the ceramic-composite-tooth restorative complex. The success of bonding to tooth relies on adequate preparation and conditioning of the surfaces involved, namely the ceramics (etching and silane application) and the mineralized dental tissues (etching of the enamel, conditioning of the dentin). For both enamel and ceramic surfaces, etching procedures combined with the use of a liquid resin have demonstrated their efficiency and longevity in extreme oral conditions.[17,18] If a substantial accessible area of dentin has been exposed by the preparation, local application of a dentin bonding agent (DBA) is recommended. In spite of encouraging results, the absolute reliability and clinical performance of the dentin bond still are impaired by the composite polymerization shrinkage and stresses resulting from thermal dimensional changes.[19,20] The choice of the restorative method has a critical impact on the behavior of the dentin–resin interface.[21] In addition to the aforementioned variables, dentin is a heterogeneous substrate, and it is difficult to predict the overall behavior of the dentin–resin interface. Multiple clinical parameters may be involved within the same tooth, such as the preparation

Figure 5. Major functional and morphologic modifications in the adult. The patient complained about the instability of existing composites restoring the incisal edges of upper anterior teeth. A *and* B, *The issue was both esthetic (short, aged teeth) and functional (thinned enamel, insufficient anterior guidance).* C, *The initial model revealed the loss of tooth morphology, affecting the facial surface of enamel.* D, *An additive wax-up reestablishing both the proximal crests and the original volume of the tooth is imperative when planning porcelain veneers. A silicon matrix of the wax-up was used as a reference for tooth reduction.* E, *In vivo, a significant space was found between the preexisting surface of the tooth and the future restoration. This procedure allowed the saving of a consistent amount of tooth substance.* F, *In spite of the thin preexisting enamel, tooth preparation was confined to enamel on both central incisors.* G *and* H, *The final situation was functionally stable and displayed balanced esthetics and an improved lipline as well as intact and healthy periodontal tissues.*

depth, previous pathologies, and contamination by dental products applied to the tooth.[22,23]

Clinically, two methods may be applied to promote dentin adhesion when placing indirect bonded restorations. The first and conventional approach consists of delaying the application of the DBA (acid etching followed by the application of the primer liquid and the bonding resin) until the last treatment stage, when proceeding to luting the veneer. To avoid incomplete seating of the restoration, it is usually recommended to keep the adhesive resin uncured when placing the veneer. It is assumed that the pressure of the luting composite during the seating of the veneer may create a collapse of demineralized collagen fibers and subsequently affect the adhesive interface cohesiveness.[21,24] More recently, a new approach was proposed to optimize DBA application.[25,26] Because the DBA appears to have a superior potential for adhesion when applied to freshly prepared dentin, its application is recommended immediately after the completion of tooth preparation, before the final impression itself. A substantial clinical advantage is that this precautionary measure protects the pulpodentinal organ and prevents sensitivity and bacterial leakage during the provisional phase. The use of a filled adhesive facilitates the procedure.

EDUCATIONAL SITUATIONS: CROWN-FRACTURED INCISORS

The use of porcelain veneers is particularly interesting in the presence of crown-fractured incisors with short clinical crowns or insufficient residual tooth structure to provide adequate stability for a conventional type of fixed prosthetic restoration. The clinical case shown in Figure 6 represents one end of the spectrum in which veneer restorations permit the maintenance of tooth vitality in spite of a severe breakdown of tooth structure. The benefit of this approach is significant for two additional reasons: (1) it allows maximum preservation of tooth substance and (2) it prevents the use of costly, more invasive and risky procedures (root canal therapy, use of an endodontic post, core buildup and full crown coverage).

The strength of the tooth–restoration complex is an important clinical concern when one is restoring extensively fractured incisors; so is the exact definition of the restorative design, i.e., whether the missing tooth substance should be replaced using (a) the veneer alone, (b) a composite buildup along with the veneer, or (c) the fractured tooth fragment itself along with the veneer. A surprising answer was given in an assessment of strength by Andreasen et al,[10] who used veneered sheep incisors in a load-to-failure test and found ultimate strength of 28.2 MPa, 20.2 MPa, and 21.0 MPa, respectively. These values are well above the strength of intact teeth, which in a similar experiment by Munksgaard et al fractured at an average 16 MPa.[27] Therefore, the use of a simplified approach (ceramic only without composite buildup) to the restoration of crown-fractured incisors could be justified (see Figure 6). However, one may question the biomechanical behavior of single teeth restored with extremely rigid and strong coronal restorations. For instance, using in vitro simulated impacts, Stokes and Hood clearly demonstrated that the excessive strength of conventional prosthetic restorations, such as gold and metal–ceramic crowns, yielded root fractures that would be difficult to restore.[9]

Modulation of restoration strength might be considered, to avoid stress transfer and catastrophic failures at the level of the root. The combination of both composites and ceramics seems theoretically appropriate to reproduce the original stiffness of the tooth and to modulate the tooth–restoration strength. However, no scientific investigations have been conducted to define, when restoring extensive loss of dentin, the optimal configuration of the restoration and related thicknesses of composite and ceramic; in fact, few scientific articles specifically have addressed the problem of internal stress distribution, stress

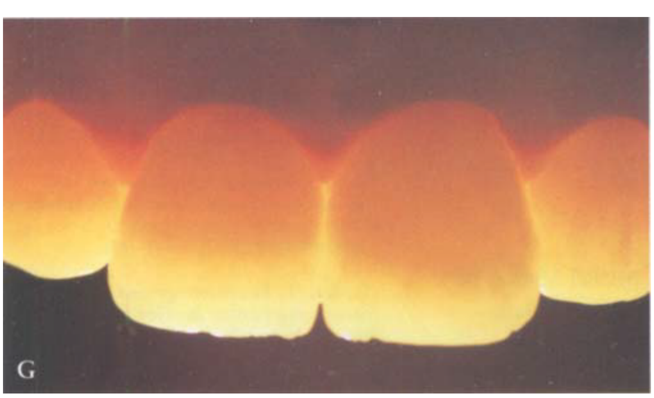

Figure 6. Crown-fractured incisors restored with veneers. A *and* B, *The pulp was not exposed despite the extensive loss of tooth substance on the right maxillary central incisor.* C, *Silicon matrices (obtained from an additive wax-up restoring the original thickness of enamel) were used as a reference to guide the realization of reduction grooves.* D, *The preparation is confined to enamel except for the fractured surface.* E *and* F, *Bonded porcelain laminates allowed the preservation of tooth vitality, the respect for the surrounding soft tissues, and the reestablishment of an attractive smile line.* G, *In vivo transillumination with an optical fiber shows how the "ceramic-only" design allowed the dental technician to use specific dentin-like porcelains to ensure an optimal optical transition between the intact half of the tooth and the bulk of the restoration.*

transfer, or tooth stiffness after the placement of porcelain veneers.[7,28] Clinicians often prefer the simplified design using ceramic alone even to replace missing portions of dentin since the procedure is straight forward and features optimal esthetic results (see Figure 6, E–G). The dental technician can use specific porcelains for the accurate reproduction of the anatomy and optical characteristics of dentin (opaque dentin for adequate translucency and fluorescent stains for adequate luminescence). Most composite resins do not allow such precise characterization. However, with regard to biomimetics, ceramic-only designs may present an excessive strength. In case of recurrent trauma to the crown this could generate a fatal root fracture or at least the loss of an additional portion of the tooth. These assumptions now require experimental validations using the latest generation of dentin adhesives, since the dentin bond proves to be an essential determinant in the fracture pattern and fracture mechanics of the tooth.[29]

REMAINING CONCERNS AND CONCLUSIONS

Even though the combination of composite and ceramic seems to be the best means to reproduce the behavior of the intact tooth, there is still a concern of the additive effects of the curing contraction and high thermal expansion of certain composite resins. The latter has been shown to have a significant influence in the development of post-bonding flaws if used as a thick luting agent and demonstrated marginal leakage when placed as a whole veneer.[30–33] The crack propensity of porcelain may be significantly reduced by providing the restoration with a favorable configuration, namely providing a sufficient and homogeneous thickness of ceramics combined to a minimal thickness of luting composite.[31,32] Tooth reduction as well as minimal application of the die spacer during laboratory procedures undoubtedly represent key elements in this matter. The wear properties of ceramics may be another potential issue in this total performance picture of porcelain veneers, as they are for porcelain inlays or traditional PFM crowns.[34–36] Here again, biomimetics significantly contributes to the development of more "friendly" and bioactive materials with self-healing properties. They constitute a possible and promising answer to the problem of wear.[37,38] For the future, the bioactivity of ceramics offers the potential of bonding to tooth without using composite resins,[39] avoiding the time-consuming traditional bonding procedures.

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