Adhesively restored anterior maxillary dentitions affected by severe erosion: up to 6-year results of a prospective clinical study

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Abstract

In case of severe dental erosion, the maxillary anterior teeth are often particularly affected. Restoring such teeth conventionally (ie, crowns) would frequently involve elective endodontic therapy and major additional loss of tooth structure. A novel, minimally invasive approach to restore eroded teeth has been developed and is currently being tested in the form of a prospective clinical trial, termed The Geneva Erosion Study. To avoid crowns, two separate veneers with different paths of insertion have been used to restore the affected anterior maxillary teeth, regardless of clinical crown length and amount of remaining enamel. This treatment is called The Sandwich Approach.

Objectives: The purpose of this case series study was to analyze the mid-term clinical outcome of maxillary anterior teeth affected by severe dental erosion that were restored following the Sandwich Approach.

Materials and methods: Twelve consecutively consulting patients (mean age: 39.4 years) suffering from advanced dental erosion have been enrolled in the study and were subsequently treated. Due to the late interception of the disease, all patients needed a full-mouth rehabilitation, which was performed without any conventional crowns. At the level of the maxillary anterior teeth, a total of 70 palatal indirect composite restorations and 64 facial feldspathic ceramic veneers were delivered. Both types of veneers were adhesively luted with a hybrid composite. Clinical reevaluations were performed 6 months after insertion of the veneers, and then annually, using modified United States Public Health Service (USPHS) criteria. Marginal adaptation, marginal integrity (seal, absence of infiltration), status of pulp vitality, postoperative sensitivity, esthetics, and restoration success/failure, were the principal clinical parameters analyzed. Results: After an up to 6-year observation time (mean observation time 50.3 months for the palatal veneers and 49.6 months for the facial veneers), no complete or major failure of the restorations was encountered. On the basis of the criteria used, most of the veneers rated Alpha for marginal adaptation and marginal seal. Secondary caries or endodontic complications were not detected. Using visual analogue scale analysis, the patient-centered satisfaction revealed a high esthetic and functional acceptance of 94.6%.

Conclusions: Compared to conventional crown preparation, restoring compromised maxillary anterior teeth by means of 2 veneers prevents excessive tooth structure removal and loss of tooth vitality. Questions on the longevity of this new treatment arise, due to the nonfavorable initial status of the teeth to be restored (eg, lack of enamel, sclerotic dentin substrate and short clinical crowns). The clinical performance of the teeth treated following the Sandwich Approach seems promising, since none of the treated teeth lost their vitality, no failure of any of the restorations was detected, and the patients' overall satisfaction was high. Even though further investigation is needed to determine the clinical long-term performance of the described treatment modality, the encouraging mid-term results (biological, esthetic, and mechanical success) clearly question if conventional crowns in the anterior maxillary segments can still continue to be considered the best and only option to treat this particular population of patients.

Fig 1 Sixteen-year-old patient with a very "healthy" oral condition. No caries or periodontal pathologies were detected. However, at attentive examination, both mandibular first molars revealed a loss of enamel, dentin exposure, and missing antagonistic contacts. The patient suffered from early dental erosion related to an excessive consumption of acidic beverages.

Introduction

The loss of tooth structure related to the presence of acids not produced by bacteria is called dental erosion. The first article that could be found in MEDLINE about this subject is from 1945.[1] Since then, several authors have been investigating the mechanisms of the acid attack, the co-factors responsible and the preventive measures for avoiding the tooth destruction.[2-9]

In contrast, only few articles have been published on the clinical treatment of this condition, mostly only at the level of case reports.[10-32]

This discrepancy reflects both a certain confusion and a lack of awareness among clinicians, not yet ready to recognize and treat dental erosion with the same strict measures implemented for other diseases, such as dental caries.

Nowadays, however, due to the vertiginous increase of the prevalence of dental erosion, especially among young individuals, clinicians become increas-

ingly aware of the need to adequately counsel and treat these patients. Nevertheless, confusion persists on when and how the therapy should best be performed (Fig 1).

Dental erosion and tooth destruction

Spontaneously, patients most often seek dental treatment only when they have pain or if there is an esthetic concern.

Since patients affected by dental erosion rarely present symptoms of thermal or tactile sensitivity (except patients affected by psychiatric problems, such as bulimia), esthetics is the most common reason to seek a dental consultation.

In case of dental erosion, typically the palatal aspect of the maxillary anterior teeth appears to be the most affected part of the dentition, particularly in case of an intrinsic etiology (eg, gastric reflux, psychiatric diseases)[33] (Fig 2). At an early stage, the acid-caused de-
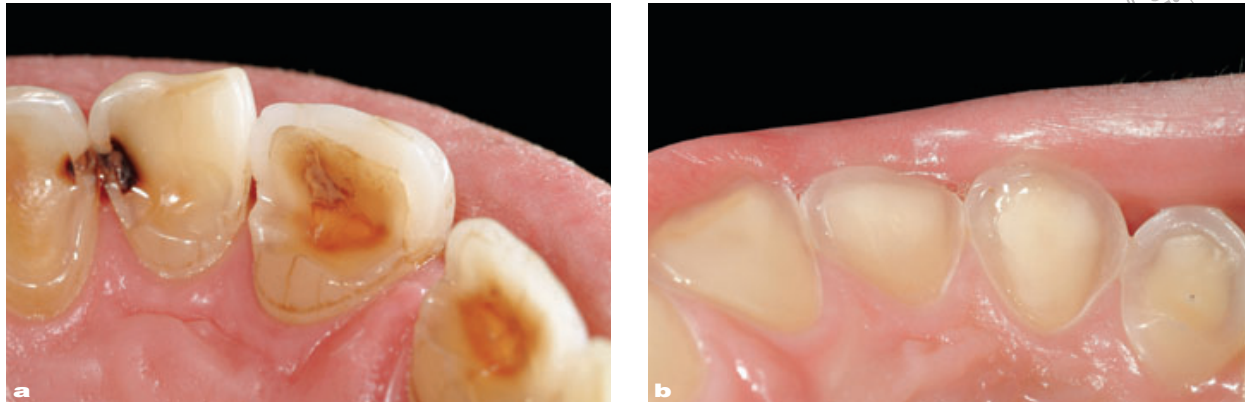
Fig 2 Palatal aspect of two different patients affected by dental erosion. In the less severe case (left), the incisal edges are thinner, but still maintained; in the second example (right), the undermining of the palatal surfaces was more conspicuous and the incisal edges had completely fractured off. Often a diagnosis of eventual parafunctional habits is used to justify the tooth structure loss. However, looking at the contact points with the antagonistic dentition, in this second patient, it was impossible to identify wear facets.

Fig 3 Patient affected by severe dental erosion. The two central incisors have lost almost half of their original clinical crown length. The patient was unaware of the degree of their destruction, since the slow supraeruption of the teeth had kept their incisal edges always at an almost correct position. Unusually, in this patient the mandibular anterior teeth did not supraerupt. Furthermore, the patient developed a gummy smile.

struction can be very subtle and thus difficult to discover due to the somewhat hidden location of the palatal tooth surfaces, especially where there is a slow progression of the disease. Eventually, the palatal destruction will affect the facial aspect of the teeth, leading to the weakening and ultimately shortening of the incisal edges. However, due to the slow change, patients may not be fully aware of the amount of tooth destruction. In fact, due to compensatory supraeruption, the fractured incisal edges may remain positioned almost at the same place of the original incisal edges (Figs 3 and 4).

In addition, due to the scarcity of information about dental erosion, patients do normally not associate the changing of the shape of the anterior teeth with the

Fig 4 Smiles of three different patients affected by severe dental erosion. All of them sought treatment for esthetic reasons. None of them reported thermal of tactile sensitivity. Even though they were aware of the changes in their dentition, they did not realize to what extent. This lack of ability to analyze the tooth damage is explained by both the supraeruption of the maxillary anterior teeth (fractured incisal edges almost aligned with the other teeth) and by the conservative way of smiling acquired with time (tight lips and teeth in contact).

etiology of the excessive presence of acid in their mouth (eg, bulimia, gastroesophageal reflux, excessive consummation of acidic beverages and food). On the contrary, many of them report a previous diagnosis of parafunctional habits (ie, bruxism) done by clinicians to justify the fracturing of the incisal edges. This diagnosis is often difficult to accept, since corresponding wear facets on antagonistic teeth are missing (Fig 5).

Only when the labial tooth structure – undermined by the destructive combination of erosion and the focal attrition of the antagonistic teeth – fractures off and the clinical crowns suddenly appear extremely reduced in length, do patients

become aware of their dental problem (esthetic awareness). As a result, patients only seek treatment spontaneously when irreversible damage has already taken place and costly restorative treatments are required (Fig 6).

The interception of cases of dental erosion at an early stage (thinning of the palatal enamel layer), when preventive measures are the only necessary treatment, would be ideal and clinicians should attentively examine every patient, especially the young ones, for initial signs of loss of tooth structure (erosive wear). In case of late diagnosis or voluntarily postponed treatment, when both the palatal aspects and the incisal

Fig 5 Thirty-year-old patient. Ten years earlier, a diagnosis of bruxism was made to explain the degradation of the patient's dentition. An occlusal guard was prescribed and worn constantly, as illustrated in (b). During our consultation, not only were there no corresponding wear facets on the antagonistic teeth, but the patient could not even bring the opposing occlusal surfaces in close antagonistic contact. Hence, the parafunctional habit was not the correct diagnosis. On the contrary, the patient was suffering of dental erosion related to an excessive consumption of acidic beverages.

Fig 6 Intraoral view of a patient affected by severe dental erosion at the initial consultation. His chief complaint was the changing of the shape of his anterior teeth. Even though the maxillary anterior teeth were severely damaged, the patient did not report any symptoms of pain. He also presented the typical signs of instability of the occlusion due to severe loss of tooth structure, a supereruption of the mandibular anterior teeth and the altered occlusal plane (reverse smile), accompanied by an accentuated curve of Spee.

edges of the maxillary anterior teeth are compromised, conventional crowns for all involved teeth are often proposed to the patient.

In case of severe dental erosion, however, the amount of the remaining tooth structure (especially in deep bite patients) could be misleading and one might be surprised about how little of the original tooth is left after conventional crown preparation (Fig 7). What still remains of these maxillary anterior teeth after years of degradation would be removed, in the case of crown therapy, to guarantee the path of insertion of the crowns (mesial and distal aspects)

Fig 7 Deep bite patient suffering from erosion. The facial aspect of the teeth is almost intact but very undermined. In this patient, crown preparation would lead to the almost complete removal of the coronal part of the tooth and elective endodontic treatment would then be necessary.

and to provide sufficient space for the esthetic ceramic veneer (facial surface).

After completing the tooth preparation, there may be insufficient tooth structure left to provide adequate retention and resistance form for conventional crown restorations.

As a consequence, elective endodontic therapy may become necessary. This would currently be considered a biological failure. Due to the young age of these patients, before delivering crowns, clinicians should take in consideration that problems may arise in the long run, especially in cases of devitalized teeth. Furthermore, maxillary anterior teeth affected by erosion that are subsequently devitalized and prepared for crowns may not feature a sufficient ferrule. This may significantly increase the long-term risk of root fracture (mechanical failure).

In addition, the darker color of the devitalized roots may later become visible due to gingival recession, frequently associated with crown therapy, leading to an esthetic failure.

Geneva Erosion Study

Since 2005, a clinical trial has been underway at the School of Dental Medicine, termed the Geneva Erosion Study. The unique feature of this prospective clinical study is that it comprises patients affected by dental erosion, from the most severe to the very early stages of the disease.

Hence, to be included in the study, it is sufficient to present signs of dentin exposure related to dental erosion. Another important aspect of the study is that all treatments are exclusively based on adhesive technology, following the principle of minimal invasiveness. No conventional crowns are delivered, unless already present, and needed to be replaced.

Since only minimally invasive treatments are considered in the Geneva Erosion Study, to fully preserve the remaining tooth structure despite the triangular shape of the affected maxillary anterior teeth, two distinctly different paths

of insertion are necessary to restore the palatal and the facial aspects without sacrificing interproximal tooth structure. This specific technique, termed the Sandwich Approach, consists in reconstructing the palatal aspect first with a composite palatal veneer, indirect or direct (IPV/DPV), followed by the restoration of the labial aspect in the form of a ceramic facial veneer (FV) (Fig 8).

Thanks to adhesive technology, there is no need for retention of these restorations by friction in 360 degrees as is needed for conventional crowns. On the contrary, the tooth structure must be preserved to a maximum to have a larger surface for adhesion, even by preserving unsupported enamel on the facial aspect. As a result of its minimal or, ideally, absent tooth preparation, the described Sandwich Approach is also clearly less traumatizing in terms of maintaining the vitality of compromised pulps.

Moreover, even if the presence of sufficient remaining tooth structure could avoid elective endodontic treatments, crown preparation could still be too aggressive, under the light of various additional procedures, such as provisional fabrication, impression, bisque try-in, and final cementation, which all require the exposure of the prepared tooth to the oral cavity, including inevitable dehydration of the dentin (Fig 9).

In accordance with several studies, a loss of vitality after the completion of conventional crown therapy may be part of possible adverse events (postponed biological failure). The incidence of vitality loss is generally underestimated because of the difficulty in testing pulp vitality with crowns in place.[34-40] In contrast, testing of the tooth vitality through

Fig 8 Sandwich Approach (or bilaminar approach). Palatal composite veneer and facial ceramic veneer. Only with two separate restorations and two different paths of insertion, the triangular shape of eroded maxillary anterior teeth can be restored without unnecessary sacrifice of tooth structure.
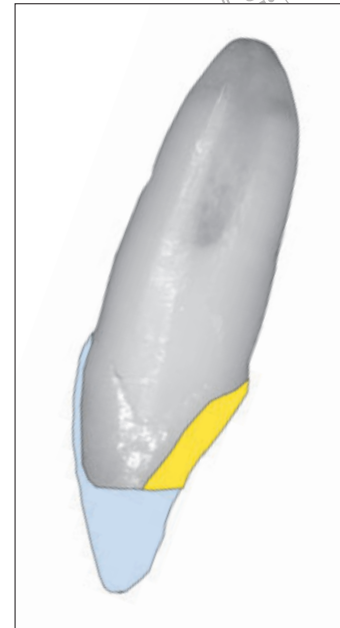
the thin facial veneer is easily achieved in the context of the sandwich approach. This is a notable advantage, not only because eroded teeth are always at higher risk to spontaneously lose their vitality, but also because endodontic therapy can be achieved through the palatal composite veneer, without jeopardizing the remainder of the restored tooth.

This is not possible, for instance, in cases of all-ceramic crowns, where the endodontic access on the palatal aspect may lead to microfractures of the core and subsequent failure of the restoration.[41] To decide which treatment is best indicated for the maxillary anterior teeth affected by dental erosion, the Anterior Clinical Erosion (ACE) classification had been developed and was consequently implemented in this study[42] (Fig 10).

Fig 9 Patient affected by severe dental erosion restored with conventional crowns. Although elective endodontic therapy was not planned, the left maxillary central incisor lost its vitality during the treatment. Note the alteration (swelling, texture, color) of the marginal gingiva (right) in comparison with the initial status.

Fig 10 Maxillary occlusal view of the palatal aspect of two patients, both affected by dental erosion. Intercepting an ACE class I patient (a), when the enamel is thinner, but still intact, will lead to the complete resolution of the dental problem, since only preventive measures are necessary at this stage. An ACE class IV patient (b), instead, needs a full-mouth rehabilitation. The difference of age between these two patients was only 10 years. The dental erosion etiology was the same (bulimia).

The ACE classification is based on 5 clinical parameters considered fundamental for the evaluation of the severity of the erosion damage and the prognosis of the treatment.

Considering the loss of palatal and facial enamel, the exposure of the dentin on the palatal aspect, the fracture of the incisal edges, and the loss of vitality, the ACE classification divides the patients into 6 categories.

ACE class I patients, who present only a thinning of their palatal enamel, are not treated, but informed and instructed to prevent further damage of their dentition. Hence, this category of patients was not enrolled in the study.

ACE class II patients, who only feature initial signs of dentin exposure on the palatal aspect of the maxillary anterior teeth, were included in the study, as they required a protective type of treatment. The rationale behind this very early intervention is to preserve the incisal edges from further damage. Early non-invasive restorations (composite restorations) are preferred in comparison to conventional crowns delivered later in life to these patients.

ACE class III patients, characterized by fractured incisal edges (but less than 2 mm of the original length), and by an extensive exposure of the palatal dentin, were also included in the Geneva erosion study. Direct or indirect composite restorations are perfectly suited for this category of patients to reconstruct the palatal aspect without tooth preparation.

However, in case of significant shortening of the clinical crown, palatal veneers may be insufficient to satisfy the patient's esthetic request. Consequently, additional restorations (ceramic facial veneers) are necessary to complete the treatment. This is the case of ACE classes IV and V where the incisal edges are fractured more than 2 mm and the Sandwich Approach is recommended.

Finally, patients are classified ACE class VI when they present at least one devitalized tooth among the maxillary anterior dentition. The loss of pulp vitality could be related to both severe tooth destruction and severe intensity of the acid attack, as it is the case in bulimic patients. For ACE class VI patients the Sandwich Approach is also indicated, to avoid the devitalization of the remaining teeth. Following an identical clinical protocol, 12 ACE class IV to VI patients have been consecutively treated and followed up at the School of Dental Medicine of the University of Geneva, from 2006 to 2012. All procedures were performed by the same clinician (FV). The aim of the present prospective case series study was to evaluate the clinical performance up to 6 years of the restored maxillary anterior teeth.

Materials and methods

Seven men and five women with a mean age of 39.4 years (range 27 to 64 years) volunteered in this study. All patients presented to the University of Geneva, School of Dental Medicine with the common chief complaint that their teeth were deteriorating functionally and esthetically, namely the incisal edges of the maxillary anterior teeth. At the baseline examination, all patients were suffering severe dental erosion; the anterior teeth were the most affected, with conspicuous damage of the incisal edges.

Table 1 List of the patients classified according to their gender, age, ACE classification and time of function of the final restorations, delivered at the level of the maxillary anterior teeth

Patients	Gender		Age (years)	ACE classi-fication	Teeth treated with FV (tooth no.)	Teeth treated with PV (tooth no.)		Time of clinical service (months) PV & FV		
								FV	PV	
						Direct	Indi-rect		Direct	Indirect
1	M		31	V	13–23		13–23	65		68
2	M		46	IV	13–23	22	13–11 21, 23	68	72	72
3	M		50	V	13–23		13–23	48		53
4	F		42	IV	13–23	13–23		66	67	
5	M		64	VI	13–23	13–23		67	71	
6	F		35	IV	13-23	13–23		76	71	
7	F		27	IV	12–22		13–23	24		18
8	F		36	V	12–22		13–23	33		36
9	F		31	IV	12–22		12–22	44		47
10	M		40	IV	13–23		13–23	50		54
11	M		34	IV	12–22		13–23	23		43
12	M		37	IV	13–23		13–23	31		32
Total	5 F	7M		8 IV 3 V 1 VI	64	19 D	51 ID			
MEAN			39.4			70		49.6	50.3	

Interestingly, before entering the Geneva Erosion Study, only three patients were aware that the cause of their dental status was related to acidity in the oral cavity. According to the ACE classification, there were eight ACE class IV, three ACE class V, and one ACE class VI patients (Table 1).

Before starting the treatment, a consultation with an expert in craniomandibular disorders and one with a gastroenterologist were provided. Only the patients affected by bulimia (5 out of 12) were not sent for an evaluation of their digestive system. For all the others an upper gastrointestinal endoscopy and 24 hour pH monitoring were performed. The respective investigations confirmed in 6 patients the presence of gastroesophageal reflux and those individuals received medical treatment accordingly (proton pump inhibitors therapy). For the remaining patient, the only possible etiology of the observed erosion was excessive ingestion of acidic beverages (eg, carbonated sodas), a habit con-

firmed later by the patient. For all patients, dental treatment started before the erosive process was under control.

The rationale behind this choice was to cover and seal the exposed dentin as soon as possible, and thereby protecting the involved teeth from further damage caused by both the acid attack and the attrition of the antagonistic teeth (dentin and pulp protection).

A vitality test was performed using cotton pellets soaked with coolant (Endo-Ice Refrigerant Spray, Coltène/ Whaledent) on all the teeth (except when radiographies confirmed a previous root canal treatment), and surprisingly the majority of teeth were still vital, despite the advanced loss of tooth structure. Interestingly, only three patients complained about thermal tooth sensitivity.

A concomitant diagnosis of parafunctional habits (bruxism and/or clenching) was registered for 4 of the 12 patients; however, before treatment only 2 patients were wearing an occlusal appliance (guard).

Three patients were also smokers. This is particularly important information when it comes to the evaluation of the status of the periodontal tissues.

All 12 patients received a full-mouth adhesive rehabilitation, following the same protocol (the 3-step technique).[43-45]

An increase in vertical dimension of occlusion (VDO) was arbitrarily decided on the casts articulated in maximum intercuspation position (MIP), and transferred to the mouth by means of posterior provisional composite restorations (step 2 of the 3-step technique). Due to the presence of these posterior restorations, an anterior open bite was created.

Following an equal protocol, after 1 month of functioning without anterior guidance, six palatal composite restorations were placed and the anterior contacts reestablished (step 3 of the 3-step technique). According to the given interocclusal space, it was decided for each individual patient whether direct or indirect restorations were best suited. When the distance to the antagonistic teeth was more than 1 mm, an indirect approach was preferred. Overall, 51 indirect and 19 direct restorations were placed.

When the indirect approach was selected, the palatal aspect of the maxillary anterior teeth was prepared according to the same protocol as for the direct approach, before taking the final impression. First, the palatal dentin was cleaned with a nonfluoride-containing pumice prophylaxis paste. The exposed sclerotic dentin was gently roughened with a coarse diamond bur, to remove the most superficial layer, and then immediately sealed. The surface was etched for 15 seconds with 37% phosphoric acid, abundantly rinsed with water, dried, and then the primer and the bond were applied, following the manufacturer's instructions (Optibond FL, Kerr). A flowable composite was subsequently used to thicken the hybrid layer (Tetric flow T, Ivoclar Vivadent). Prior to taking the final impression, the periphery of the prepared surface was gently touched with a slowly rotating diamond bur to remove any eventual adhesive resin from the enamel finish line.[46-50]

Also still prior to impression taking, the interproximal contact zones between the maxillary anterior teeth were slightly opened using thin diamond strips, and
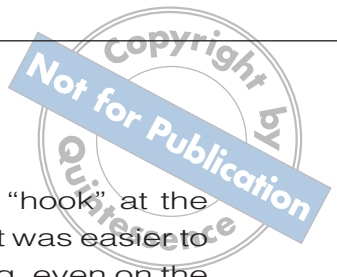
the incisal edges smoothened by minimally removing the unsupported enamel prisms. Both interventions were carried out to facilitate the fabrication of optimal working casts. Anesthesia was not necessary for the described procedure, except in the case of one bulimic patient who presented tooth hypersensitivity before the treatment. No provisional restorations were delivered after the final impression was taken. This is a clear indication that sealing of the exposed dentin was highly efficient in terms of oppressing potential thermal sensitivity, and that the absence of any incisal edge preparation did logically not affect esthetic appearance. After one week, the IPVs were adhesively inserted, one at a time, under rubber dam insulation. The previously sealed palatal dentin was air abraded (Cojet, 3M, Espe), the peripheral enamel etched (37% phosphoric acid for 30 s), and the adhesive resin (Optibond FL) applied, but not cured to avoid the risk for incomplete seating. The composite veneers were also air abraded (Cojet), subsequently cleaned in an ultrasonic alcohol-containing bath, prior to the application of three coats of silane (Silicup, Heraeus, or Monobond plus, Ivoclar Vivadent), and dried in the oven for 1 min at 100°C. An adhesive layer (Optibond FL) was then applied to the silanized surface without light curing. A warmed-up hybrid composite (Miris, Coltène/Whaledent) was subsequently placed to the cementation surface of the restorations, used as a luting agent and light cured (90 s for each surface). The open interproximal contact areas facilitated the described bonding procedures, from positioning of the palatal veneer to excess removal. Thanks to the presence of a composite "hook" at the level of the incisal edges, it was easier to achieve correct positioning, even on the "slippery" palatal surfaces. The hooks were subsequently removed during finishing and polishing. The described restoration of the palatal aspect of the maxillary anterior teeth provided the patients with both inter-maxillary centric occlusion contacts and anterior guidance.

Restoration of the labial aspect of the maxillary anterior teeth was completed with ceramic facial veneers (FV), carried out generally a few weeks after the insertion of the palatal composite restorations. As a preparatory measure, alginate impressions of the maxillary arch were taken and an additive wax-up of the facial aspect of the six or four maxillary anterior teeth was performed. Each patient was then scheduled for a so-called mock-up visit, where the final shape of the facial veneers was tested and determined according to esthetic and functional criteria. Once the patient's approval was obtained, respective tooth preparation was performed following the same protocol. The interproximal contact areas, kept open after bonding of the palatal veneers, were further adjusted with an abrasive diamond-coated metallic strip. A light chamfer was prepared at the cervical level, following the curve of the marginal gingiva, with no need for extending the preparation to the gingival sulcus, since the color of the underlying tooth structure was perfectly natural. As the palatal aspects, previously restored with composite veneers, were considered an integral part of the respective teeth, no particular effort was made to place the preparation margins on tooth structure. In the present study, the incis-

al edge was shortened and the length created by the palatal veneer was removed (butt joint preparation). Particular attention was paid to rounding off all the line angles. In case of dentin exposure, immediate dentin sealing (Optibond FL and Tetric flow) was performed, as previously explained. A retraction cord size zero was applied (GingiBraid, DuxDental), and the impression taken (Express 2 3M ESPE). Temporary restorations were performed chairside using a provisional composite material (Telio, Ivoclar Vivadent), molded to the prepared teeth with a well-adapted silicon key, previously used for the diagnostic mock-up. Since no cement was utilized, sufficient retention for two weeks of clinical service was achieved by both the contraction of the product and the presence of minimal interproximal excess. A total of 64 FVs were fabricated in the laboratory using feldspathic porcelain (Creation CC, Willi Geller International), following standard laboratory procedures, including refractory dies. Three different commercial dental laboratories were involved.

The bonding of the facial veneers was carried out 2 weeks after impression taking, and followed the protocol developed and published by Magne et al.[51-54] The rubber dam was placed and each veneer was bonded individually. The intaglio surfaces of the ceramic veneers were etched for 60 s with hydrofluoric acid, and then placed in alcohol and ultrasonically cleaned for 6 min. Subsequently, three coats of silane (Silicup, Heraeus, or Mondobond plus, Ivoclar Vivadent) were applied and dried in the oven for 1 min at 100°C. Finally, a coat of bond (Optibond FL, Kerr) was applied without curing. The sealed dentin on the pre-

pared teeth was air abraded (Cojet, 3M Espe), and the existing enamel etched (37% phosphoric acid) for 30 seconds. A coat of adhesive resin (Optibond FL) was applied, but not cured before seating the restoration. A warmed-up composite was then applied to the restorations (Miris, Coltene/Whaledent), before positioning them on the teeth and light curing. Any excess of the luting composite was carefully removed before the polymerization; however, after removal of the rubber dam, additional cleaning of the gingival margins was performed if necessary, but only using a scalpel. No rotary instruments were used. Finally, static and dynamic occlusion was checked and adjusted if indicated.

After the restoration of the maxillary anterior teeth, the patients' treatment continued with the replacement of the provisional posterior restorations by final adhesive restorations (full-mouth adhesive rehabilitation).

Finally, at the end of the treatment, a Michigan-type occlusal appliance was delivered to patients also affected by parafunctional habits (4 out of the 12 patients). All the patients enrolled in the Geneva Erosion Study are scheduled for an annual check-up where intra- and extraoral photographs are taken, occlusion is controlled and several clinical parameters are evaluated; consequently all the records of the patients participating in this study were updated yearly. All clinical evaluations were performed using standard dental diagnostic instruments and visual inspection with the aid of magnification (x2.5) (ErgoVision HD Telescope; SurgiTel) and a state-of-the-art dental unit with overhead lighting.

Table 2 Modified USPHS Criteria applied for the clinical evaluation of five clinical parameters selected for the study

Characteristics	Rating	Criteria
Marginal adaptation	Alpha	No defect
	Bravo	Minor defect
	Charlie	Major defect
	Delta	Margin fracture
Marginal seal	Alpha	No discoloration
	Bravo	Superficial discoloration
	Charlie	Deep discoloration
	Delta	Secondary decay
Restoration failure	Alpha	None
	Bravo	Discrete crack
	Charlie	Chipping
	Delta	Bulk fracture
Postoperative Sensitivity (air)	Alpha	None
	Bravo	Moderate
	Charlie	Severe

Table 3 Detailed description of the teeth restored with various types of palatal and facial veneers

Teeth	Palatal Veneers		Facial Veneers
	Direct (DPV)	Indirect (IPV)	
Canines	6	16	16
Lateral incisors	7	17	24
Central incisors	6	18	24
Total restorations	19	51	
	70		64

The subjective patient satisfaction is measured by using visual analogue scales (VAS).

The VAS analyzed not only the patient's satisfaction from an esthetic point of view, but it also took into consideration the patient's perception of the overall treatment time, how the treatment was structured, and how the different therapeutic phases were handled by the clinician. Descriptive statistical methods were implemented to analyze the data collected from this clinical trial.

The restorations were analyzed following the well-established US Public Health Service (USPHS) evaluation method.[55,56] The scoring system is defined as follows (Table 2):

- Alpha: excellent result, restorations without changes or clinically ideal.
- Bravo: acceptable result, restorations with changes that are clinically acceptable and do not require replacement.
- Charlie: unacceptable, restorations with major changes that require replacement to prevent further deterioration.
- Delta: unacceptable, immediate replacement necessary.

Results

A total of 70 palatal and 64 facial restorations were delivered to the 12 patients participating in the study (Table 3).

The noticeable discrepancy between the number of PV and FV (70 versus 64) is explained by the systematically applied strategy of minimally invasive dentistry adopted in the Geneva Erosion Study. In fact, 2 of the 24 canines did not require palatal veneers, and 6 (25%) of the same 24 canines did not

need facial veneers. When it comes to the central and lateral maxillary incisors, however, all had to be restored with both palatal and facial veneers, due to the advanced state of dental erosion.

Six of the 24 maxillary canines involved in the study were considered perfectly rehabilitated after the restoration of their palatal aspect with palatal veneers. Consequently, no further treatment was considered necessary for these teeth.

To avoid bias, the recall assessments were not performed by the same clinician who had placed the restorations. Seventy palatal veneers were delivered, 51 were created indirectly in the laboratory (indirect palatal veneers, IPV) and 19 fabricated directly in the patient's mouth (direct palatal veneers, DPV). The mean observation time of the palatal veneers was 50.3 months (range: 1.5 to 6 years of follow-up). The results of the clinical evaluation are presented in Table 4. As for the palatal composite veneers, the overwhelming part of the scores corresponded to "Alpha", one can consider the overall clinical integration of these restorations as excellent.

In fact, all PVs were rated "Alpha" for all the four clinical parameters, except for two restorations.

In patient number 10, one palatal veneer was rated "Bravo", due to a slight defect at the palatal junction between the facial and the palatal veneers, detected at the 3-year follow-up. The observed defective margin, however, did not show signs of infiltration.

Table 4 Clinical results for the palatal veneers (PVs). Numbers 1 to 12 correspond to the patients examined (I= Indirect; D=Direct)

PV	Rating	1		2		3		4		5		6		7		8		9		10		11		12		Veneers	
		D	I	D	I	D	I	D	I	D	I	D	I	D	I	D	I	D	I	D	I	D	I	D	I	D	I
Marginal adaptation	Alpha	6		1	5		6	6		6		6			6		6		4		5		6		6	19	50
	Bravo																				1						1
	Charlie																										
	Delta																										
Marginal seal	Alpha	6		1	5		6	6		6		6			6		6		3		6		6		6	19	50
	Bravo																		1								1
	Charlie																										
	Delta																										
Restoration failure	Alpha	6		1	5		6	6		6		6			6		6		4		6		6		6	19	51
	Bravo																										
	Charlie																										
	Delta																										
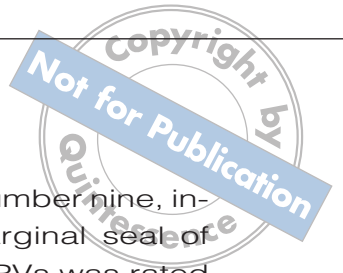
Table 5 Clinical results for the facial veneers

FV	Rating	1	2	3	4	5	6	7	8	9	10	11	12	Veneers
Marginal adaptation	Alpha	6	6	6	6	6	6	4	4	4	5	4	6	63
	Bravo										1			1
	Charlie													
	Delta													
Marginal sea[l]	Alpha	6	6	6	6	6	6	3	2	4	5	3	5	58
	Bravo							1	2		1	1	1	6
	Charlie													
	Delta													
Restoration failure	Alpha	6	6	6	6	6	6	3	4	4	6	4	6	63
	Bravo							1						1
	Charlie													
	Delta													
Postoperative sensitivity	Alpha	6	6	6	6	6	6	4	4	4	6	4	6	64
	Bravo													
	Charlie													

In patient number nine, instead, the marginal seal of one of the six PVs was rated "Bravo", because it was considered to be superficially discolored.

The clinical performance of the 64 FVs over a period of 1.9 to 6.3 years was favorable too. The mean observation time was 49.6 months. All FV restorations were rated "Alpha" for the marginal adaptation, except one, rated "Bravo".

The marginal seal of all the FV was rated "Alpha", except for six teeth, where the veneers showed a superficial discoloration at the cervical margin ("Bravo") at the 3-year follow-up. The described discolorations were subsequently removed by superficial polishing (Table 5).

None of the restorations (FV and PV) failed over the observation period of the present study. One facial veneer was rated "Bravo", due to the presence of a crack, visible two weeks after cementation. At the 2-year follow-up the crack was stable and not discolored. The patient was not capable to detect it, unless deliberate dehydration of the restoration was provoked using air stream. Thermal testing was performed using a cotton pellet soaked with coolant
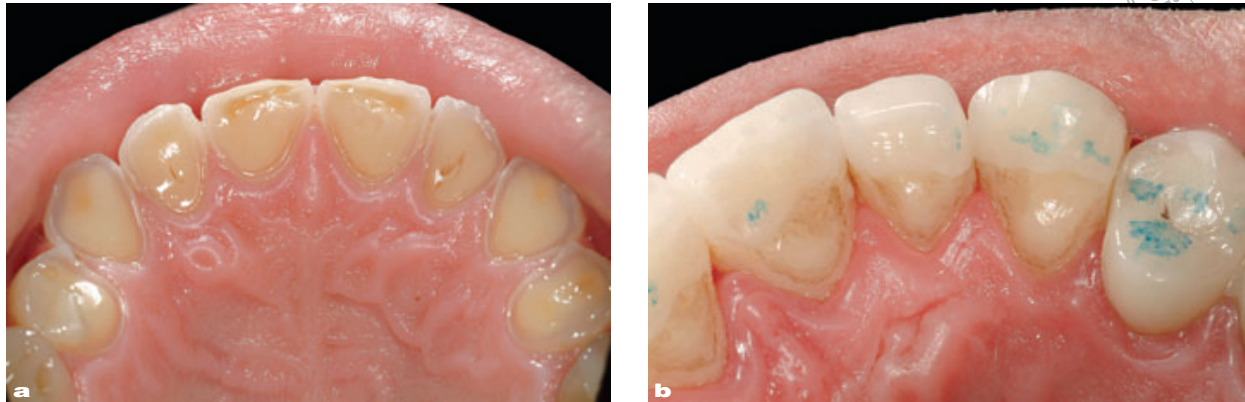
Fig 11 Palatal view, initial status and 6-year follow-up of a heavy smoker patient included in the Geneva Erosion Study. Note the no infiltrated margins between the composite palatal and the ceramic facial veneers. The picture was taken without any previous cleaning of the restorations.

(Endo-Ice® Refrigerant Spray; Coltène/Whaledent). Thanks to the ultrathin facial veneers, it was possible to reliably assess the vitality of all the restored teeth. None of them lost their vitality during the treatment or the following observation time (Figs 11 to 14).

No signs of postoperative sensitivity were observed, and the hypersensitivity present in some patients before the treatment, was successfully eliminated after completion of the restorations. Gingival and plaque indices were recorded using standardized techniques assisted by periodontal probe and explorer. Assessment of the biologic parameters, ie, bleeding on probing (BOP) and plaque control record (PCR), confirmed favorable conditions.

BOP was below 20% for 11 of the 12 patients with an average of 13.3%, and the PCR was only above 20% in one patient, with an average of 9.8% (Table 6). The favorable clinical outcomes were confirmed with a high mean VAS score of 94.6%.

Finally, neither muscular discomfort nor temporomandibular joint problems became apparent at any moment of

Table 6 Summary of gingival and plaque recordings.

Patient details	N = 12
BOP	13.3%
PCR	9.8%

treatment or thereafter. Bonded porcelain veneers represent a highly reliable treatment modality when it comes to the restoration of either structurally or esthetically compromised maxillary anterior teeth. This is particularly true for the related esthetic outcome (esthetic success), as documented by numerous clinical studies.[57-61] Various authors have shown survival rates above 90% over a period of 10 years of clinical service for this type of restorations. Only minor problems, which did not require the replacement of the restoration (mechanical success), were reported.[57,58,62] Moreover, contemporary facial porcelain veneers are clearly less traumatizing for the pulp than traditional full coverage preparations, due to the reduced amount of tooth structure removed during prep-
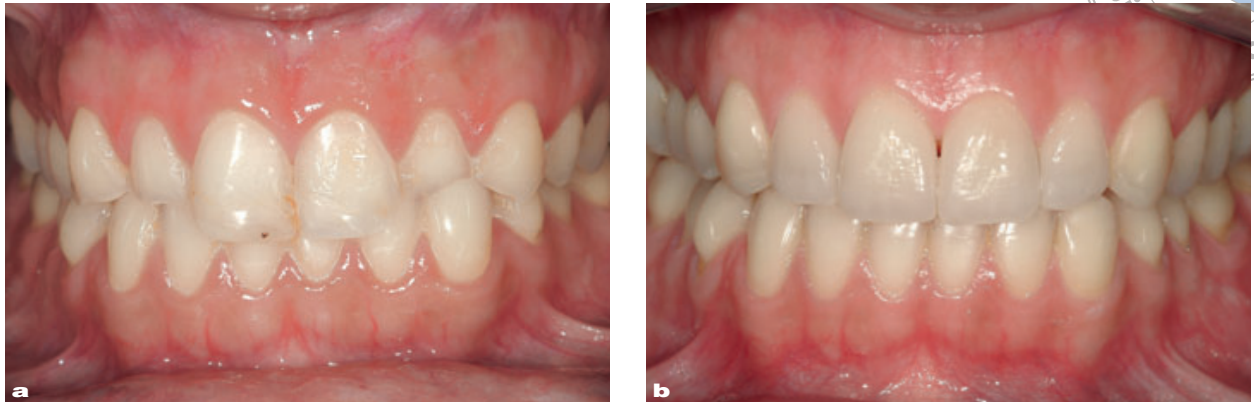
Fig 12 (a and b) Initial status and after 3-year follow-up of a bulimic patient included in the Geneva Erosion Study.
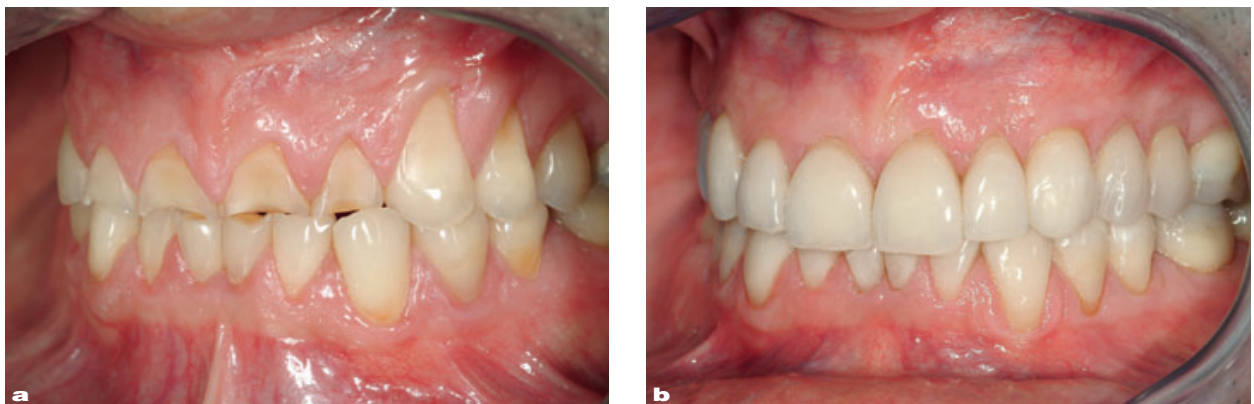
Fig 13 (a and b) Initial status and 5 year folllow-up. This patient was the most extreme case included in the Geneva erosion study. The maxillary anterior teeth were restored with two veneers (palatal and facial), with minimal if any tooth preparation. After 5 years of clinical service, the veneers presented still excellent conditions, despite the initial lack of facial enamel, the type of occlusion, and reduced clinical crown hight. None of the teeth lost their vitality.

Fig 14 Bonding procedure of six facial ceramic veneers in the patient illustrated in Fig 13. Note the conspicuous increase of length obtained with the veneers.

aration (biological success).[63] However, clinicians are still reluctant to extend the indications for veneers to more severely compromised anterior maxillary dentitions. Veneers have been, in fact, advocated to change only minimally the shape and/or color of slightly affected teeth, since the presence of a high percentage of enamel as well as the initial height of the surface to be restored are considered crucial for long-term success.[64-69] Consequently, in case of severe dental erosion, 360 degree prepar-

ation and the establishment of adequate retention and resistance form are still considered by numerous clinicians as being more reliable than bonding. This conception was, and still is, leading to a high number of crowns delivered to restore such teeth. Unfortunately, according to this strategy aiming to provide more long lasting restorations, additional precious tooth structure must be sacrificed. In this study the involved anterior maxillary teeth were all ranging from ACE class IV to VI, representing a real challenge for the restorative dentist. The population of patients treated featured not only extensive dentin exposure, but frequently also short clinical crowns. In fact, the final restoration length often almost doubled the initial one. For the majority of the teeth involved in this study, endodontic treatment would have been required, as well as crown lengthening, to obtain adequate retention and resistance form for the restorations if conventional crown preparation had been performed (biological failure). In order to preserve the remaining tooth structure to a maximum and to not further weaken the already compromised dentition, two separate veneers (a palatal and a facial one) were delivered for each maxillary anterior tooth treated. While there is a strong body of evidence in the literature regarding the longevity of so-called classical facial veneers, reliable data on the clinical performance of dual veneer restorations is still lacking.

When the present study was initiated, concerns were raised on how two veneers, made of different materials (composite on the one hand and ceramics on the other) could be predictably bonded, not only between them, but also to ex-

tremely compromised tooth structure, ie, mainly eroded sclerotic dentin.

In fact, the dentin was often extensively exposed on both the palatal and the facial aspect, and its quality was all but ideal for predictable bonding, due to its either sclerotic or over-etched character. Before 2012, there was literally no robust scientific documentation available as a basis for determining the correct way of bonding to such eroded dentin.[70]

Without adequate literature support, it was decided – in the context of the Geneva Erosion Study – to apply a uniform protocol consisting of the gentle removal of the most superficial dentinal layer, followed by etching the remaining dentin for only 15 s, and to subsequently seal this conditioned surface. The follow-up examination confirmed the efficacy of the described approach in terms of thermal isolation as no postdelivery sensitivity of the restorations was reported. Interestingly, in case of existing tooth sensitivity before treatment, it was largely improved, if not completely eliminated after completion of the restorations.

In retrospect, the choice of maintaining a maximum of the remaining tooth structure, and the strategy of placing two independent restorations with two different paths of insertion (no problem with undercuts and therefore no need for removal of the mesial and distal marginal ridges) has been validated by the favorable outcome in terms of biological success presented in this study. All the teeth that had tested vital before treatment kept their vitality throughout all follow-up examinations. It should be underlined that several of the restored teeth presented an initial clinical crown height that was almost doubled by the final veneers.

This was even the case in some patients where occlusal parafunctional habits had been diagnosed at the initial examination. Also under these specific conditions, no failure of the described adhesive restorations was observed to date, indicating that the patients were obviously compliant in terms of systematically wearing their occlusal appliances.

In terms of longevity of anterior bonded ceramic restorations, Magne et al[71] reported a 0% frequency of clinically unacceptable fractures (ie, fractures that would require a complete replacement of the restoration. These findings were also confirmed by other authors, who published similar low failure percentages.[72-74] In the present study, only one patient presented a crack at the the mesial surface level of a central incisor's facial veneer. The crack was discovered after the delivery of the restoration at the 1-week follow-up.

The respective veneer was extremely thin, due to the current tendency to limit tooth preparation to a minimum. Polymerization shrinkage of the luting composite could have led to critical stress concentrations between the adhesive interface and the ceramic subsurface.[75]

The crack was stable at the 2-year follow-up, revealing an intact adhesive bond between tooth, composite and ceramic. This finding is in line with observations reported by other authors on the presence and evolution of cracks in ceramic veneers, and similarities drawn relative to cracks in enamel. Secondary caries did not occur at any of the veneer restorations, despite the fact that the ceramic facial veneers were extensively in contact with the palatal composite veneers at the palatal aspect. In

a more recent *in vitro* study published by Gresnigt et al,[76] it was concluded that ceramic veneers bonded to composite restorations provided favorable results, supporting the previous clinical findings of the same group.[77]

Only one tooth in the present study was rated "Bravo", the defect was considered acceptable in the palatal junction between the facial and the palatal veneer and it did not require repair.

However, since Peumans et al[59] reported that veneers with restoration margins located in composite fillings showed a secondary caries incidence of 10% after 10 years, long-term follow-ups are needed to determine how the union between the two veneers will age.

Despite the rather short observation time of this study and considering the severely compromised initial status of the teeth involved, the combination of separate palatal and facial veneers showed very promising results up to 6 years of follow-up, revealing a survival rate of 100%.

Thanks to the Sandwich Approach, the remaining tooth structure was preserved to a maximum, no respective mucogingival surgery was necessary (except one case, done for esthetic reasons) and no elective endodontic trewatment was performed.

At the level of the anterior teeth, the enamel was reduced but still present at the cervical (palatally), mesial, distal and facial aspects providing a strong scaffold for the restorations. Thanks to the Sandwich Approach this enamel framework was almost completely preserved. In 2008, Vailati and Belser formulated the Tennis Racket theory,[43] to justify the bilaminar technique. According to this

theory, the author believes that the presence of an enamel framework is crucial for the strength of the anterior teeth, like the marginal ridges in the premolars. Any attempt to remove it may lead to a weakening of the entire structure and an increase of the tooth flexibility. The palatal veneers not only reinforce the tooth, but most of all stop the progression of its destruction. Thanks to the bonding to the remaining peripheral enamel, these restorations show a very satisfactory mid- to long-term clinical performance.

Finally, all the teeth maintained pulp vitality, even when the erosive destruction of the palatal aspect had almost exposed the pulp. No hypersensitivity was developed and, if present before the treatment, the tooth protection related to the adhesive techniques had clearly improved the original symptoms.

It could be concluded that the early intervention to protect the pulp without waiting for the erosive pathology to be under control played a key role in the tooth vitality preservation.

The purely additive strategy utilized in case of the palatal veneers, which required no tooth preparation, proved its validity as translated by 100% biological success. Despite the recommendations made by several authors,[78] in the authors' opinion dental treatment should be initiated as soon as possible in case of erosion patients, even when the pathology is still active, as in the case of bulimic patients.

Conclusion

The promotion of long-lasting oral function should be the primary objective in any

comprehensive dental treatment plan. In this context, three different success criteria should be considered, ie, biological, mechanical, and esthetic success.

It appears obvious that a restoration should integrate as close as possible to the adjacent dentition (esthetic success) and it should also be sufficiently resistant to last a reasonable amount of time (mechanical success).

What is not always explained correctly to patients is the amount of tooth structure "iatrogenically" removed to achieve the two above-mentioned elements of success and the associated negative consequences in the long run.

In fact, preservation of mineralized tooth structure and maintenance of pulp vitality (both directly linked to biological success), are not often considered by patients as key factors at the moment of accepting proposed dental therapies.

Typically, patients affected by severe dental erosion present an already extensive loss of mineralized tooth structure. Hence, their restorative therapy should be even more based on a minimal invasive approach to guarantee the so crucial biological success.

As conventional crowns are clearly considered a too aggressive approach, this cohort of patients affected by dental erosion have been treated in accordance with the guidelines of the "3-step technique," using exclusively adhesive techniques with the maximum preservation of tooth structure.

In this article, the up to 6-year follow-up of 12 patients affected by severe dental erosion and subsequently treated with minimally invasive adhesive techniques, is illustrated. Based on the mid-term results, it has been

shown that two separate veneers (one facial, one palatal) can reliably restore a maxillary anterior tooth, even in case of severely compromised eroded dentition. Thus the described treatment approach clearly represents an excellent and tooth structure-preserving alternative in comparison to full crowns. These encouraging results from a biological, mechanical, and esthetic success point of view, should seriously question if conventional full crowns in the anterior sextants are still indicated to treat this particular population of patients.

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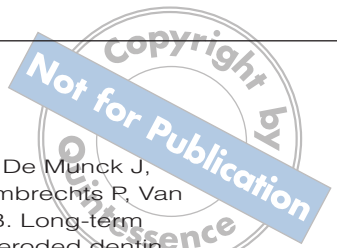
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