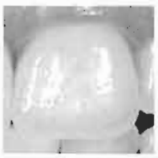
Clinical Performance of Novel-Design Porcelain Veneers for the Recovery of Coronal Volume and Length



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The present study evaluated the clinical performance of bonded porcelain veneers (PV) restoring substantial coronal volume and length in the anterior dentition. Forty-eight PVs were placed in 16 patients, with systematic coverage and reconstitution of the incisal edge, including well-defined anterior guidance. A standardized protocol comprising diagnostic steps that integrate additive waxups and acrylic mockups was used. PVs were fabricated using feldspathic and low-fusing porcelains in a refractory die technique. Incisal overlaps featured freestanding porcelain spans ranging from 1.5 to 5.5 mm. After a mean clinical service of 4.5 years, 13 clinical parameters for each tooth and 4 parameters that applied to persons were recorded. Permutation tests evaluated the effects of margin location, incisal edge span of porcelain, overbite, opposing contact location, and restoration age on ceramic failure and clinical marginal adaptation and seal. At recall, 100% of the veneers were satisfactory with minor interventions. The effect of slight marginal defects and porcelain cracking was negligible. Biologic, periodontal, and esthetic parameters showed excellent results, which were supported by 100% patient-reported satisfaction. All patients felt comfortable with the newly defined anterior guidance. Aging was negligible, and there were no significant effects of margin location ($P > 0.08$), incisal edge span of the ceramic, or overbite ($P > 0.22$) on ceramic failure and marginal performance. Minor alterations of the palatal margin, however, tended to be more frequent compared to facial locations, and were found especially when the opposing tooth contact in centric occlusion was located on the palatal margin ($P = 0.028$). Bonded ceramic restorations represent a reliable, effective procedure to restore extensive coronal volume and length in the anterior dentition. (Int J Periodontics Restorative Dent 2000;20:441–457.)

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Owing to a number of clinical studies, porcelain veneers (PV) have matured into a predictable restorative concept in terms of longevity, periodontal response, and patient satisfaction.[1–5] A number of researchers has gained confidence in bonded ceramic restorations, and the indications for their use have been broadened significantly,[6–11] resulting in newer preparation designs.[8,11,12] Unexplained post-bonding cracks, which initially deterred clinicians from using PVs, have been understood and explored experimentally.[13–15] Internal stress distribution and the parameters responsible for craze-line formation have been investigated, and preparation design has been adjusted accordingly.[15–18]

Based on these considerations, restoration of crown-fractured incisors (Figs 1 and 2) and worn-down dentitions have been proposed as new indications for PVs. This approach has to be considered with special attention because its success and reliability could result in substantial treatment improvements comprising both the medicalbiologic aspect (ie, economy of sound tissues and maintenance of tooth vitality) and the socioeconomic context (ie, decrease of costs when compared to traditional and more invasive prosthetic treatments).[19] Theoretical foundations for such an indication have been documented by experimental and numeric studies[6,7,17,19,20] showing the sufficient strength and adequate biomechanical behavior of the tooth-restoration complex provided that adequate design and thickness of the restoration are respected.

Little information, however, is available from medium- to long-term studies about the clinical performance of PVs featuring long incisal edge spans of porcelain, and clinicians have legitimate concerns when placing such restorations. Therefore, the aim of the present in vivo study was to evaluate the medium- to long-term clinical performance of PVs involved in extensive reconstruction of crown volume and length for the anterior dentition.

Method and materials

In this investigation, 48 PVs were placed in 16 patients (11 women and 5 men) between 1992 and 1996. The mean patient age at baseline was 33 years (range 18 to 52 y). All patients were consumers of tea and 81% were coffee drinkers, but only 19% were smokers. PVs were placed to recover function and esthetics of anterior teeth, which always involved a significant volume of the crown portion, ie, coverage and reconstitution of the incisal edge (or cusp tip) including well-defined anterior guidance (Fig 2c). Patients were selected according to recent guidelines[11] that extend the spectrum and indications of PVs to more perilous situations including *(1)* major morphologic modifications and restoration of incisor prominence and *(2)* restoration of extensive crown fractures and worn-down anterior dentitions. No other selection criteria were used to include the patients; specifically, occlusal pattern, overbite, oral hygiene, or amount of remaining enamel were not considered in selecting these patients. Teeth were distributed as follows: 39 maxillary teeth (23 central incisors, 11 lateral incisors, and 5 canines) and 9 mandibular teeth (2 central incisors, 3 lateral incisors, 2 canines, and 2 premolars).

Restorative procedures

A single operator performed all clinical procedures. Tooth preparation technique followed a standardized protocol including the use of a diagnostic template that integrates additive waxups (Figs 3a and 3b) and acrylic mockups as described elsewhere.[21] The axial reduction was carried out with tapered round-ended burs (starting with reduction grooves) and controlled using silicon guides (Figs 1c and 3c), ultimately generating spaces ranging between 0.7 mm (facially) and 5.5 mm (incisally, depending on the remaining tooth substance) but with a minimum 1.5-mm incisal clearance. A facial and proximal light chamfer was created in the form of a paragingival margin respecting the scalloped gingival contour (Fig 1c). The palatal finish line either consisted of a butt or very conservative hollow chamfer, except for one case of long chamfer extending into the palatal concavity. For most cases, the extension of palatal margins was limited as much as possible and minimally invaded the remaining palatal surface. Localization of opposing tooth contacts was not taken into consideration. Even in cases of severe fractures, the finish line directly followed the fracture line (compare Figs 1a and 1c). Impressions were taken with polyvinyl siloxane (Extrude, Kerr).

All PVs were fabricated by the same dental technician (Oral Design Center dental laboratory) using a feldspathic porcelain (Creation, Klema) in a refractory die technique (Ducera-Lay refractory die material, Ducera). The die spacer consisted of a wax (Fixierwachs, Bredent) applied to the original stone die with a hot electric spatula to form a thin film 1 mm short of the margin. Additional firings preceded the traditional stratification technique to build up the missing portion of dentin using opaque porcelains (Fig 4). The PVs were tried on the teeth. In some instances, the last firing or eventual correction firings were carried out using a low-fusing hydrothermal glass (LFC-Duceram, Ducera).

Finally, adhesive luting procedures were performed. A rubber dam could be applied in most cases, and deflection cords were used in other situations. The inner surface of the restoration was

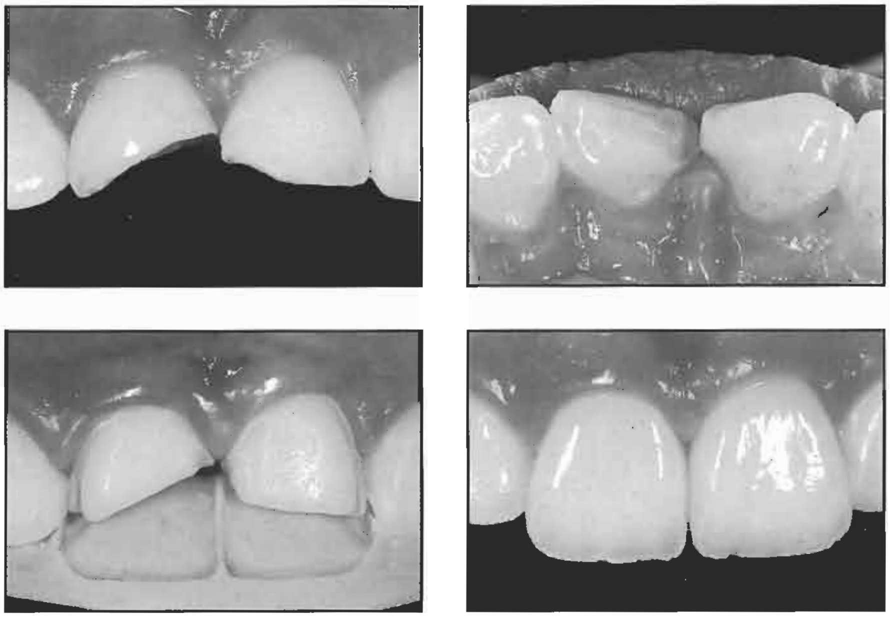


Fig 1a (left) *Treatment of crown-fractured incisors, facial preoperative view. Significant volume of central incisors was lost because of trauma.*

Fig 1b (right) *Palatal view. Fracture line ends paragingivally at mesial aspect of right central incisor.*

Fig 1c (left) *Hard tissue loss estimated at > 5 mm in height is evident (silicon index from waxup).*

Fig 1d (right) *Final bonded porcelain restorations reproducing the diagnostic acrylic mockup (not shown).*

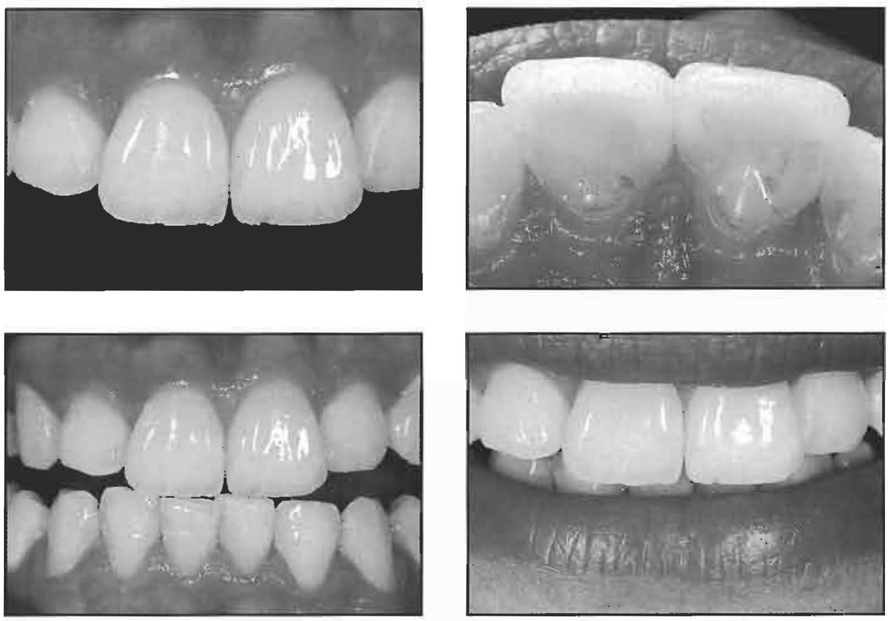


Fig 2a (left) *Unchanged situation at 4-year follow up of restored crown-fractured incisors (case shown in Fig 1; compare to Fig 1d).*

Fig 2b (right) *Slight enamel stains are detected on the palatal aspect, but clinical marginal adaptation and seal are not altered.*

Fig 2c (left) *No porcelain failures are recorded in spite of obvious function and marked anterior guidance.*

Fig 2d (right) *Optimal esthetic integration: smile line and patient's personality were respected through specific diagnostic steps.*[21]

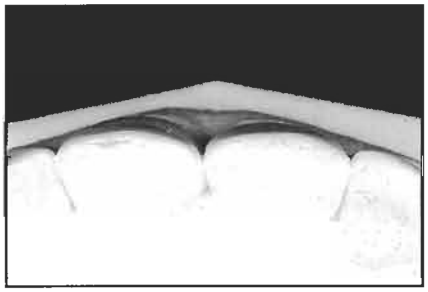


Fig 3a *Typical incisal view of study cast shows alteration of facial contours because of erosion and wear.*

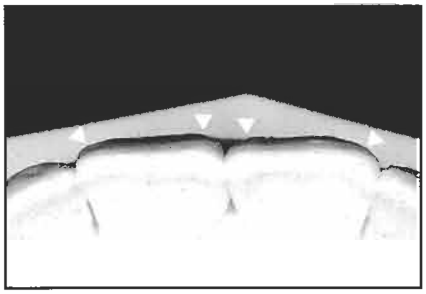


Fig 3b *Additive waxup. Original crown volume can be recovered by recreating adequate transition line angles* (arrowheads).

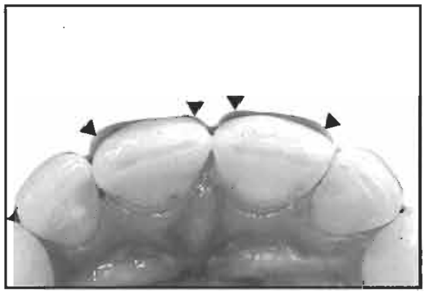


Fig 3c *Another case shows preoperative clinical control with silicon index; because of the additive waxup, a significant amount of enamel will be saved, especially at the level of the transition line angles* (arrowheads).

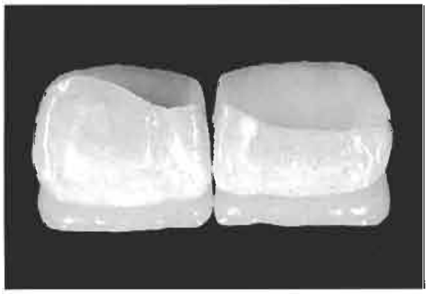


Fig 4a (left) *Novel-design porcelain veneers, palatal view.*

Fig 4b (right) *Immediate postoperative clinical view.*

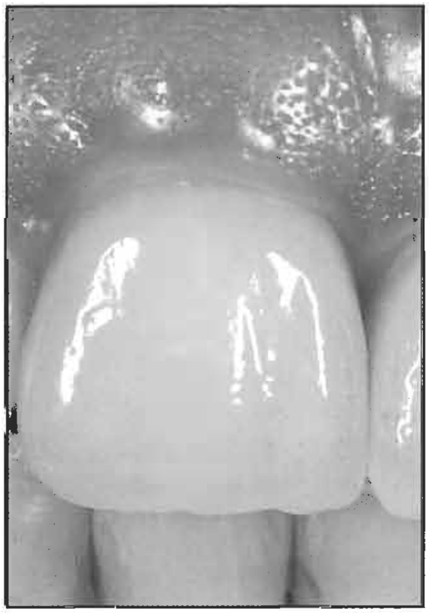


Fig 4c *Facial clinical view of right central incisor at 7-year follow up.*

Fig 4d *Radiograph shows extreme ceramic incisal edge span of left central incisor ($\approx$ 5 mm) at 7-year follow up.*

Fig 4e *Facial clinical view of left central incisor at 7-year follow up.*

etched for 90 seconds using 10% ammonium bifluoride gel (Biodent Retentionsgel, Dentsply/DeTrey). After abundant rinsing and drying, the same surface was coated with silane (Biodent Coupling Agent 90, Dentsply/DeTrey). Following etching of enamel (Ultraetch, Ultradent) and eventual use of a dentin adhesive (in case of axial dentin exposure), the prepared tooth surface and inner restoration surface were coated with adhesive resin and loaded with photopolymerizing composite (Herculite Incisal LT, Kerr). The PVs were seated with finger pressure. After the removal of excess luting composite, the margins were covered with a glycerin jelly and the curing light was applied intermittently for 120 seconds on each side of the tooth (palatal first, then facial). The margins were then finished with a scalpel and a scaler for the removal of excess resin. The occlusion was then adjusted, beginning with centric occlusion (maximal intercuspation). The occlusal features of teeth restored by PVs were identical to those applied to intact natural teeth. Particular emphasis was placed on the maintenance or reestablishment of an adequate and functional anterior guidance during mandibular excursions (laterotrusion, protrusion) regardless of whether this guidance involved the new PVs. It appeared that for 15 of the 16 individuals, anterior guidance was significantly increased through the placement of the restorations, which were previously planned and approved by the patient through appropriate diagnostic steps.[21]

Color slides were made preoperatively, after tooth preparation, and immediately postoperative (baseline). All restorations showed excellent esthetics and perfectly adapted margins at baseline. No splints or protection devices were provided to the patient.

Evaluation procedures

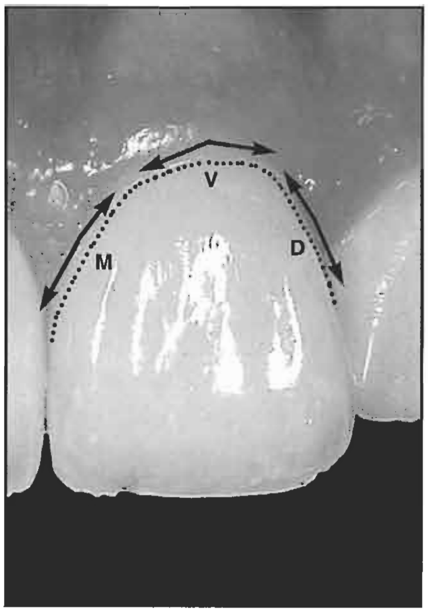
All patients were recalled during summer 1999, when the restorations were 3 to 7 years old. During this assessment, color slides of the restorations were taken, and 13 clinical parameters were recorded for each tooth, as were another 4 parameters that applied to persons: occlusal comfort, social impact, personal impact, and patient satisfaction (Table 1). Clinical parameters included color match, porcelain failures (cracks, chipping, and fractures), marginal performance (adaptation and seal, caries recurrence), tooth vitality, and occlusal pattern (location of opposing tooth contact and overbite). Four locations on each tooth were considered in the evaluation of marginal performance: mesiofacial, midfacial, distofacial, and palatal (Fig 5).

Criteria were recorded by 2 evaluators following an index system (Table 1). In cases of disagreement, a consensus was reached by discussion. During the same session, polyvinyl siloxane impressions were taken, and corresponding models made of epoxy resin (Epoxy Die, Ivoclar) were used to verify measurements such as interarch relationships, ie, location of opposing tooth contact (on ceramic/on palatal margin/other), overbite, and incisal edge span of ceramic material. This last value was averaged on 3 measurements made at mesial, central, and distal aspects of the incisal edge (Fig 6).

Table 1 Parameters recorded for the study and summary of results

Parameter	Results
1. Restoration age (per patient)	54 ± 17 mo
2. Color changes (per tooth)	
1 = none	98% (47/48)
2 = slight change	2% (1/48)
3 = moderate change	0
4 = severe change	0
3. Porcelain failures (per tooth)	
1 = none	85% (41/48)
2 = discrete crack	10% (5/48)
3 = obvious crack	2% (1/48)
4 = chipping	2% (1/48)
5 = bulk fracture	0
4. Location of opposing contact (per tooth)	
A = enamel	35% (17/48)
B = margin	21% (10/48)
C = ceramic	44% (21/48)
5. Marginal adaptation (4 locations/tooth)	
1 = no defects	96% (185/192)
2 = slight defect	4% (7/192)
3 = excess luting composite	0
4 = margin fracture	0
6. Clinical marginal seal (4 locations/tooth)	
1 = no discoloration	93% (179/192)
2 = superficial discoloration	7% (13/192)
3 = deep discoloration	0
7. Margin with preexisting composite (per tooth)	10% yes (5/48)
8. Bleeding on probing (per tooth)	100% no (48/48)
9. Loss of tooth vitality (per tooth)	100% no (45/45)*
10. Recurrent decay (per tooth)	100% no (48/48)
11. Tooth hypersensitivity (per tooth)	100% no (48/48)
12. Loss of surface polish (per tooth)	100% no (48/48)
13. Extent of incisal coverage (per tooth)	2.9 ± 1.1 mm
14. Overbite (per tooth)	3.8 ± 1.2 mm
15. Occlusal comfort (per patient)	
1 = guidance on ceramic OK	94% (15/16)
2 = uncomfortable guidance	0
3 = no guidance	6% (1/16)
16. Social impact (per patient)	
1 = very important	50% (8/16)
2 = positive	31% (5/16)
3 = none	19% (3/16)
4 = negative	0
17. Personal impact (per patient)	
1 = very important	63% (10/16)
2 = positive	25% (4/16)
3 = none	12% (2/16)
4 = negative	0
18. Patient satisfaction (per patient)	
1 = excellent	100% (16/16)
2 = good	0
3 = medium	0
4 = none	0

*Three teeth had already been endodontically treated before intervention.



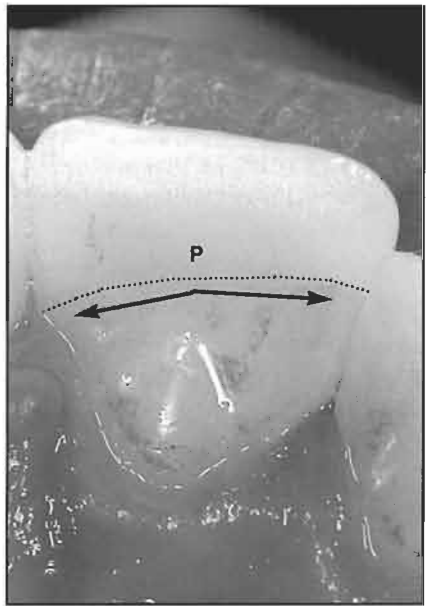


Fig 5a (left) *Assessment of cervical marginal adaptation and seal. M = mesiofacial; V = midfacial; D = distofacial.*

Fig 5b (right) *Assesment of palatoincisal marginal adaptation and seal. P = palatal.*

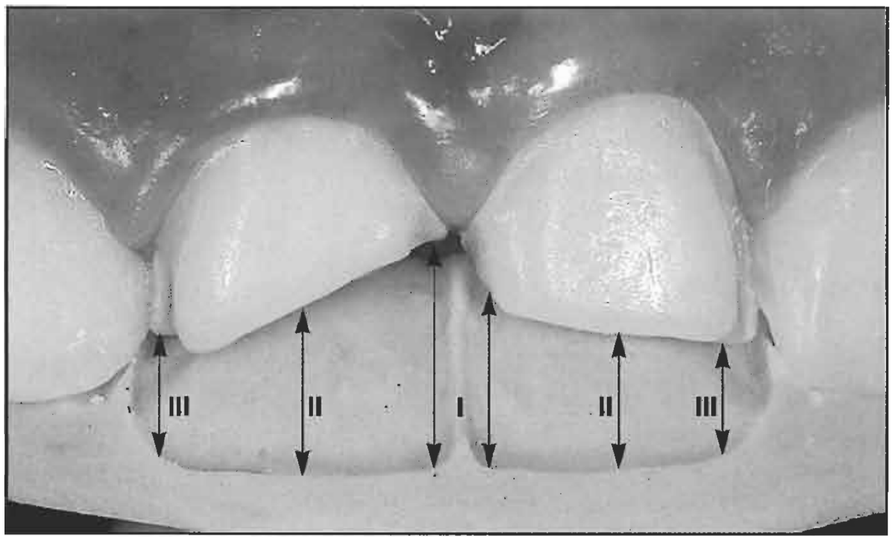


Fig 6 *Locations for measurement of incisal edge span of ceramic material: mesial* (I), *central* (II), *and distal* (III) *aspects of incisal edge.*

Null hypotheses and statistical methods

It was hypothesized that marginal adaptation and seal were *(1)* similar at all locations on the teeth, *(2)* independent of ceramic incisal edge span, overbite, or location of opposing tooth contact, and *(3)* similar at all restoration ages; and porcelain failure was *(4)* independent of ceramic incisal edge span, overbite, or location of opposing tooth contact, and *(5)* similar at all restoration ages.

The data present 2 problems. First, more than one tooth was included for most patients in the study, and all teeth have 4 aspects. This induces correlation of outcomes within (respectively) patients and teeth. Second, failures were rare, and all outcomes happened to be binary (success vs minor alterations; Table 1) or nearly so. Generalized estimating equations could, in theory, be used, but these equations depend on large-sample approximations, and for binary outcomes a large sample is one with a large percentage of failures. The solution was to test the null hypotheses using random-permutation tests (a good approximation to exact conditional tests[22]), which are defined as follows: consider the simple case in which an outcome and a predictor are measured once each per patient, eg, in a logistic regression the predictor is restoration age, the outcome is occlusal comfort (guidance comfortable vs guidance not comfortable), and the measure of relationship is the regression coefficient. In testing whether restoration age is related to occlusal comfort, the *P* value is the chance—under the null hypothesis of no relationship—of obtaining a regression coefficient as large as or larger than the coefficient estimated from the actual data. A random-permutation test simulates the null hypothesis by deliberately destroying the relationship in the data. Specifically, each subject's predictor (restoration age) is fixed, but each subject is randomly assigned an outcome (occlusal comfort) by randomly permuting the outcomes in the data set. Such a random permutation creates a pseudo data set like the original data set; the same logistic regression is estimated using these pseudo data, and the coefficient is saved. The cycle of random permutation and estimation is repeated many times, saving the estimated coefficient each time. The 2-sided *P* value from the permutation test is the fraction of such pseudo data sets that gives a regression coefficient as large as or larger than (in absolute value) the regression coefficient from the actual data. If the coefficients estimated from the pseudo data are often larger than the coefficient estimated from the actual data, then the relationship in the actual data is not statistically significant. One thousand random permutations were used for each test, which gives an excellent approximation to the exact conditional test.

More complicated situations require more complicated random permutations than the one just described. The following permutations were used.

- Outcome = marginal adaptation or marginal seal; predictor = location on tooth (hypothesis 1). This predictor is location specific. Thus, to test these relationships, each permutation randomly permuted the outcomes for the 4 aspects of each tooth in each patient. This breaks the relationship in the data between location and outcome while preserving each tooth's composite outcome and any correlations between outcomes for the same tooth or patient.
- Outcome = marginal adaptation, marginal seal, or ceramic failure; predictor = ceramic incisal edge span, overbite, or location of opposing contact (hypotheses 2 and 4). These predictors are tooth specific. Thus, to test these relationships, each permutation randomly permuted the outcomes for the teeth within each patient for the 13 patients having more than one tooth. For the 3 patients having a single tooth in the study, the outcomes were allocated randomly among the same 3 patients. This permutation breaks the relationship in the data between these tooth-specific measures while preserving any correlations between outcomes for the same tooth or patient.
- Outcome = marginal adaptation, marginal seal, or ceramic failure; predictor = restoration age (hypotheses 3 and 5). Restoration age is a patient-specific measure. Thus, to test its relationship to these outcomes, each permutation randomly permuted restoration ages across patients. (This is equivalent to permuting outcomes across patients, but computationally simpler.) This preserves any correlations between outcomes for the same tooth or patient while breaking the relationship in the data between restoration age and the outcomes.

The outcomes being all binary, Pearson's Chi-squared statistic was used as the measure of relationship for the categoric predictors (location on the tooth, location of opposing contact). For continuous predictors (incisal edge span, overbite, restoration age), the coefficient of those predictors in a logistic regression was used.

Results

A summary of results is given in Table 1. Restorations were evaluated after a mean clinical service of 54 ± 17 months, ie, 4.5 years. Biologic parameters displayed unequivocally favorable results (criteria 8 to 11; Table 1), ie, no bleeding on probing, no loss of tooth vitality, no recurrent decay, and no hypersensitivity. Except for one patient, no plaque accumulation was detected on the porcelain. Esthetic parameters also showed very commendable results (criteria 2 and 12; Table 1), ie, no loss of surface polish and only one tooth (nonvital central incisor) with a minor color alteration (undetected by the patient). These esthetic outcomes are supported by other results such as the social and personal impact of the restorative approach, which were rated maximum by more than half of the patients, and patient satisfaction, which was rated excellent by all individuals. Functional outcomes were extremely favorable. None of the patients displayed uncomfortable occlusal guidance on the restorations (only one patient did not show guidance directly on the restored teeth), phonetic problems, or any other discomfort. The worst porcelain failure consisted of one case of chipping of an incisal edge, which did not require replacement of the restoration. Other minor failures included 5 of 48 teeth with discrete cracking and one tooth with obvious cracking (undetected by the patient). Finally, marginal adaptation and seal complete this positive global performance picture, with only 4% (7/192 locations) and 7% (13/192 locations) minor alterations, respectively.

As already mentioned, a low rate of alterations was observed, which reduces statistical power for testing the hypotheses (Table 2). Consequently, in addition to discussing significant effects ($P < 0.05$), comparisons having P values between 0.05 and 0.10 (Tables 3 and 4)—testing of which would be of particular interest in a future, larger study—will also be discussed.

Outcome = marginal adaptation or marginal seal; predictor = location on tooth. The tests found no significant differences between locations. However, palatal locations tended to show more alterations of marginal adaptation and seal compared to other locations ($P = 0.076$ and 0.09, respectively).

Outcome = marginal adaptation, marginal seal, or ceramic failure; predictor = ceramic incisal edge span, overbite, or location of opposing contact. The tests found no significant relationships for incisal edge span and overbite ($P > 0.22$ in all cases). However, when the opposing tooth contact was located on the palatal margin, alterations were found more often than when the opposing tooth contact was elsewhere ($P = 0.046$). This effect was stronger when considering palatal measurements alone ($P = 0.028$). These results are supported by a similar, though weaker, result for marginal seal ($P = 0.09$).

Outcome = marginal adaptation, marginal seal, or ceramic failure; predictor = restoration age. No significant effects of aging were found. Older restorations tended to have less successful outcomes according to marginal seal; for each extra year of restoration age, the estimated odds ratio of a less successful outcome was 1.94 ($P = 0.077$).

Discussion

Because traditional PVs are expected to last 10 to 15 years,[23] the results of the present study can be considered only as preliminary (medium term). However, bearing in mind that 100% of the restorations survived over the mean 4.5-year period, a very good prognosis can be anticipated for the new proposed indications. For the patients in the study, traditional treatment approaches would have involved the removal of large amounts of sound tooth substance, with adverse effects on the pulp, gingivae, and crown biomechanics, as well as serious financial consequences. The use of adhesive technology instead provided maximum preservation of tissues (Fig 7) and limited costs, which also contributed to the absolute satisfaction of the patients. A comprehensive discussion of the present trial must include biologic, mechanical, functional, and esthetic considerations.

Fig 7a *Preoperative view shows extreme defect of hard tissues but no pulp exposure. (From Magne et al.[14] Reprinted with permission.)*

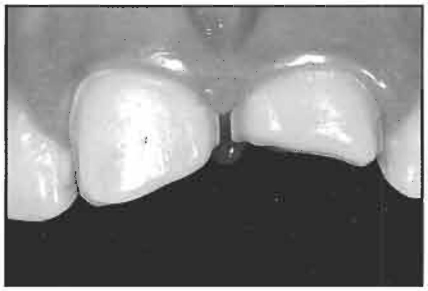


Fig 7b *Tooth preparations are carried out with maximum respect of remaining tooth substance.*

Fig 7c *Postoperative view with optimal outcome at 5 years.*

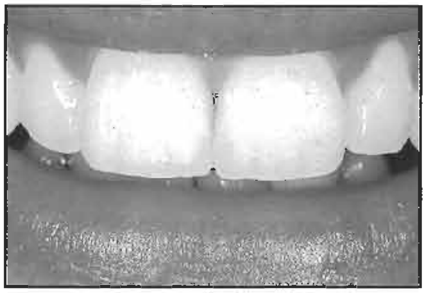


Fig 7d (left) **and 7e** (right) *Five-year follow-up view shows healthy periodontium, intact tooth-restoration complex, and harmonious smile.*

Biologic considerations

The first result to be logically discussed is the excellent periodontal response, which was first noted by Calamia in the late 1980s.[1] Owing to intrinsically favorable esthetics in the marginal area, bonded ceramic restorations do not specifically require penetration of the gingival sulcus, which prevents potential damage to the periodontal tissues. Kourkouta et al[2] even demonstrated significant reductions in Plaque Index and plaque bacteria vitality after the placement of PVs. Such results call into question the general assumption that so-called "high-end" adhesive restorations are not indicated for patients with poor oral hygiene. In fact, bonded ceramics might be the most forgiving restorations for patients struggling with oral hygiene (Fig 8). One can anticipate that the periodontium in those patients might better respond to ceramic materials considering that dental porcelain is less susceptible to accumulation of bacterial plaque in comparison to gold, resin, or even hard tooth structures.[24,25] There was no surface degradation of the ceramic material in the present study, which was corroborated by the absence of plaque accumulation. Finally, an additional significant advantage of bonded porcelain restorations from the periodontal perspective was the avoidance of crown-lengthening procedures because even very short clinical crowns could be recovered (Fig 7).

Another positive biologic outcome was the maintenance of tooth vitality throughout the entire trial. All teeth that were vital before treatment could be kept vital during and after treatment despite considerable hard tissue breakdown. This result is not surprising considering that maximum tissue preservation, including enamel, was ensured through *(1)* the adhesive approach and *(2)* the use of additive diagnostic waxups.[21]

Mechanical considerations

The use of porcelain instead of composite resins is instrumental in patient perception of the treatment as demonstrated in a clinical study by Meijering et al.[3] But porcelain also acts as the most "biomimetic" material when it comes to the replacement of significant amounts of tooth substance, perhaps because of its ability to simulate and restore crown rigidity.[26,27] Owing to their high thermal expansion and elasticity, composite veneers are not able to achieve such a goal,[28] which seems to yield unfavorable esthetics, unstable marginal integrity, and decreased survival rate.[29–31] On the other hand, even traditional porcelains such as basic feldspathic materials are able to compensate for structural tooth weakness. When used in the form of bonded veneers, including for nonvital incisors, they can contribute to the recovery of crown biomechanics.[27]

The variable incisal edge spans of ceramic material represent the main feature of the present trial (Figs 2, 4, and 7). For some of the crown-fractured incisors, the extreme design of the restorations (Fig 4a) suggests that the terminology may need to change: Can we still describe these restorations as veneers? The term "bonded porcelain restorations" (BPR) might be proposed instead. Only very limited scientific material explores this new field of indications. Wall et al[32] demonstrated that up to 2 mm of incisal edge span of ceramic could be created on mandibular incisors without affecting the ultimate coronal strength. Andreasen et al[7] might have been the first authors to advocate the treatment of crown-fractured incisors with BPRs in the early 1990s. This in vitro investigation surprisingly claimed ultimate coronal strengths of restored teeth far exceeding that of intact teeth. This conclusion might be more relevant today considering the progress of dentin adhesives.[26] It was clearly demonstrated that the potency of the concept lies in the design of the restoration, which is explained through favorable load configuration, geometry, and tissue arrangement of maxillary incisors.[17,33] As a consequence, coronal strength proves to be sufficient even when using BPRs with extensive incisal edge spans of ceramic. The present trial is supportive of these conclusions because no difference could be detected with up to 5.5 mm of freestanding feldspathic material. When compared to intact teeth, BPR-restored crowns featuring extensive incisal edge spans of ceramic are characterized by their low-stress design and increased crown stiffness.[20] However, flexibility proves to be an essential quality in any structure; otherwise, it would be unable to absorb the energy of a traumatic blow. Up to a point, the more resilient a structure, the better.[20,34] Further investigations are required to determine whether modulated strength through higher-compliance designs might be indicated (eg, by including underlying composite buildups).

The above discussion is based on the use of traditional feldspathic materials. The use of tougher, but also more sophisticated materials, such as In-Ceram Spinell, Procera (Nobel Biocare), or Empress (Ivoclar), is questionable. Using feldspathics, the worst failure in the present trial was an accidental chipping that occurred during a traumatic bite after 1 year of clinical service. The veneer was polished, and no further complications occurred in this patient, whose PVs have now been in clinical service for more than 5 years. The fact that 12% of teeth displayed cracking could justify the use of tougher ceramics. Before drawing any conclusion with regard to cracking, one should decide to what extent cracking must be considered a failure. Cracking is an unavoidable phenomenon in the aging of brittle, layered materials. In the case of enamel, cracking proves to be a natural protective process against tensile stresses,[33,35] and most intact teeth display numerous enamel cracks. The crucial role is played by the dentinoenamel junction, which acts as a crack stopper because of its specific architecture and collagen fiber arrangement.[35] The same can be said about BPRs: as long as the bond between tooth and restoration can survive, the restoration will be preserved, as was the case for 6 cracked teeth in the present study. The most supportive case was an early failure that occurred on a palatal surface after 2 weeks of clinical service. This problem did not prevent the tooth-restoration complex from serving optimally more than 3 years later (Fig 9). A basic mistake in the tooth preparation

Fig 8a *Case shows good tolerance of veneers from patient with poor oral hygiene. Immediate postoperative view after placement of porcelain veneer on maxillary left lateral incisor.*

Fig 8b *Six-year follow up shows favorable situation despite poor oral hygiene (note significant evolution of cervical lesion on maxillary right canine).*

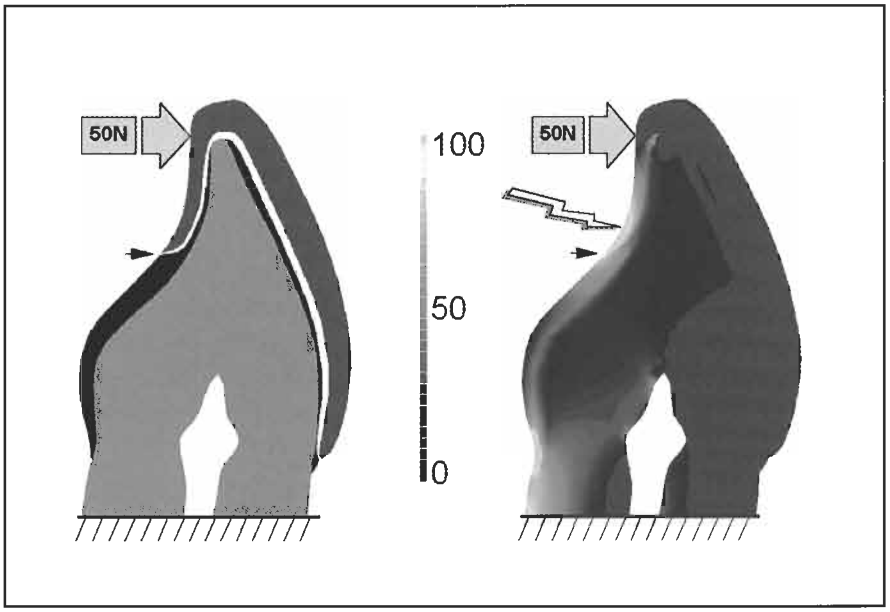


Fig 9a Left, *palatal extension of the veneer in the form of a long chamfer is not recommended because it creates thin extensions of ceramic material in areas of maximum tensile stresses.* Right, *first principal stress distribution (gray = compression; color gradation = tensile stresses).*[17] Arrows = *margin location.*

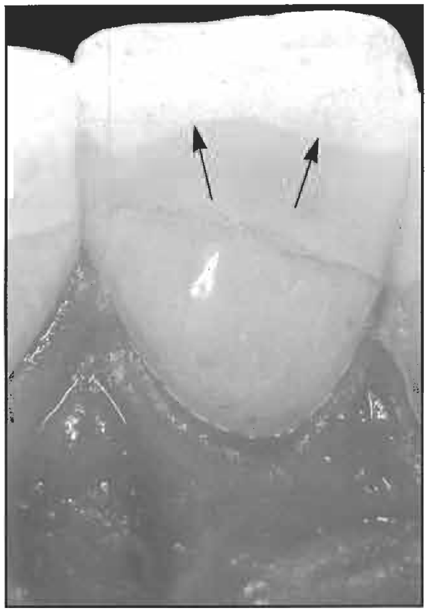


Fig 9b *Three-year follow up of palatally cracked veneer. Cracking occurred 3 years earlier because of an error in tooth preparation (see Fig 9a). No crack evolution is detected. Note accelerated degradation of palatal margin.*

(excessive invasion of the palatal surface in the form of a long chamfer) proved to be the cause of this failure.[17] Finally, crack propensity can be minimized by *(1)* soft preparations (no sharp angles), *(2)* sufficient thickness of the ceramic material,[14,15] and *(3)* adequate wrapping and design of the restoration.[16–18]

Functional considerations

Another concern might be raised by the marked anterior guidance that was created in most patients. There seems to be an association between the absence of anterior guidance, ie, open bite, and temporomandibular disorders.[36] A key element in the development of harmonious occlusion is therefore the incisal guidance,[37,38] the steepness of which is not important for neuromuscular harmony.[37] To minimize stresses during protrusive movements, some clinicians reduce the length of an esthetically correct tooth. This disastrous approach results in a reverse smile line and ages the patient's appearance by many years.[38] As proven by the results of the present trial, there should be no fear to rejuvenate the patient's smile by increasing central incisors' prominence and length because ideal occlusion refers both to an esthetic and physiologic ideal.[37,39] Another reason to avoid distributing the anterior guidance over a maximum number of teeth is the favorable mechanical behavior of BPRs discussed above. The functional features of teeth restored by BPRs can be identical to those of intact natural teeth. Particular emphasis must be placed on the maintenance or reestablishment of an adequate and functional anterior guidance regardless of whether this guidance involves the new restorations.

Esthetic considerations

The comfort and esthetic outcome was ensured by a specially developed strategy[21] to redefine an adequate smile line that also matches the unique and individual character and personality of the patient. In most cases, the prominence of anterior teeth was recovered, which inspired the important social and personal impact reported by the patients. Only one tooth (an endodontically treated incisor) showed color alteration. This now 5-year-old restoration did not integrate enough intrinsic opacity to compensate for the typical darkening of a nonvital tooth. Two other nonvital teeth in the present study did not develop such a problem because of the intrinsic opaque ceramic lining that was built into the veneer. It is generally not recommended to overlap the endodontic access cavity with the veneer or to use posts. These precautions allow an easy reentry to the crown and eventual rebleaching when required.

Overall behavior and basic strategies

Understanding of functional stress distribution on anterior teeth is certainly a key element in designing BPRs. In the case of maxillary incisors, the facial half of the tooth is mainly subjected to compressive stresses, whereas the entire palatal portion of the tooth is exposed to tensile stresses (Fig 9),[17,33] which might explain why palatal margins tended to show more degradation compared to facial locations (Fig 9b). This evolution was aggravated when the opposing tooth contact was found on the margin itself.

The overall behavior of BPRs can be most predictable when adequate treatment planning is carried out. High success rates in restoration survival and patient satisfaction are also certainly because of the use of additive waxups (Fig 3), silicon guides, and corresponding diagnostic templates (acrylic mockups).[21] These strategic elements facilitated 3 significant steps of the procedure: *(1)* maximum respect of the patient's desire in the definition of the final functional and esthetic goal, *(2)* maximum respect of the remaining thickness of enamel during tooth preparation, and *(3)* restoration of the original enamel thickness and biomimetic recovery of the crown.

No significant effect of aging was found within the evaluation period of the present trial, which gives a great insight to the potential behavior of BPRs and provides the practitioner with a noninvasive and socially restorative tool with minimum maintenance costs. One can anticipate considerable improvements such as in the treatment of crown-fractured and worn-down anterior teeth, which should reduce the need for preprosthetic interventions (eg, root canal therapy and crown lengthening) and the use of intraradicular posts. Further follow-up studies are required to confirm these results.

Acknowledgments

The authors wish to express their gratitude to Michel Magne (Oral Design Center dental laboratory, Montreux, Switzerland) for the fabrication of ceramic restorations; to Prof Ivo Krejci (Department of Cariology, Endodontics and Pedodontics, School of Dental Medicine, University of Geneva, Switzerland) for helpful contribution; to Ms Katia Capiluppi, Sylvie Roiron, and Marisa Novelle (dental hygienists, School of Dental Medicine, University of Geneva, Switzerland) for patient hygiene care; and to Ivoclar (Schaan, Lichtenstein) for generously providing the Epoxy Die material. Dr Jim Hodges was supported by the Minnesota Oral Health Clinical Research Center, NIH/NIDR P30-DE09737.

References

1. Calamia JR. Clinical evaluation of etched porcelain veneers. Am J Dent 1989;2: 9–15.
2. Kourkouta S, Walsh TT, Davis LG. The effect of porcelain laminate veneers on gingival health and bacterial plaque characteristics. J Clin Periodontol 1994;21: 638–640.
3. Meijering AC, Roeters FJ, Mulder J, Creugers NH. Patients' satisfaction with different types of veneer restorations. J Dent 1997;25:493–497.
4. Peumans M, Van Meerbeek B, Lambrechts P, Vuylsteke-Wauters M, Vanherle G. Five-year clinical performance of porcelain veneers. Quintessence Int 1998;29:211–221.
5. Fradeani M. Six-year follow-up with Empress veneers. Int J Periodontics Restorative Dent 1998;18:216–225.
6. Andreasen FM, Daugaard-Jensen J, Munksgaard EC. Reinforcement of bonded crown fractured incisors with porcelain veneers. Endod Dent Traumatol 1991;7: 78–83.
7. Andreasen FM, Flugge E, Daugaard-Jensen J, Munksgaard EC. Treatment of crown fractured incisors with laminate veneer restorations. An experimental study. Endod Dent Traumatol 1992;8: 30–35.
8. Magne P, Magne M, Belser U. Natural and restorative oral esthetics. Part II: Esthetic treatment modalities. J Esthet Dent 1993;5:239–246.
9. Walls AW. The use of adhesively retained all-porcelain veneers during the management of fractured and worn anterior teeth: Part 1. Clinical technique. Br Dent J 1995;178:333–336.
10. Walls AW. The use of adhesively retained all-porcelain veneers during the management of fractured and worn anterior teeth: Part 2. Clinical results after 5 years of follow-up. Br Dent J 1995;178:337–340.
11. Belser U, Magne P, Magne M. Ceramic laminate veneers: Continuous evolution of indications. J Esthet Dent 1997;9: 209–219.
12. El-Sherif M, Jacobi R. The ceramic reverse three-quarter crown for anterior teeth: Preparation design. J Prosthet Dent 1989; 61:4–6.
13. Barghi N, Berry TG. Post-bonding crack formation in porcelain veneers. J Esthet Dent 1997;9:51–54.
14. Magne P, Kwon KR, Belser UC, Hodges JS, Douglas WH. Crack propensity of porcelain laminate veneers: A simulated operatory evaluation. J Prosthet Dent 1999;81:327–334.
15. Magne P, Versluis A, Douglas WH. Effect of luting composite shrinkage and thermal loads on the stress distribution in porcelain laminate veneers. J Prosthet Dent 1999;81:335–344.
16. Highton R, Caputo AA, Matyas J. A photoelastic study of stress on porcelain laminate preparations. J Prosthet Dent 1987; 58:157–161.
17. Magne P, Douglas WH. Design optimization and evolution of bonded ceramics for the anterior dentition: A finite-element analysis. Quintessence Int 1999;30: 661–672.
18. Magne P, Douglas WH. Interdental design of porcelain veneers in the presence of composite fillings: Finite element analysis of composite shrinkage and thermal stresses. Int J Prosthodont 2000;13: 117–124.
19. Magne P, Douglas WH. Rationalization of esthetic restorative dentistry based on biomimetics. J Esthet Dent 1999;11:5–15.
20. Magne P, Douglas WH. Optimization of resilience and stress distribution in porcelain veneers for the treatment of crown-fractured incisors. Int J Periodontics Restorative Dent 1999;19:543–553.
21. Magne P, Douglas WH. Additive contour of porcelain veneers: A key element in enamel preservation, adhesion, and esthetics for aging dentition. J Adhesive Dent 1999;1:81–92.
22. Agresti A. Categorical Data Analysis. New York: John Wiley, 1990:59–66.
23. Friedman MJ. A 15-year review of porcelain veneer failure—A clinician's observations. Compend Contin Educ Dent 1998; 19:625–636.

24. Chan C, Weber H. Plaque retention on teeth restored with full-ceramic crowns: A comparative study. J Prosthet Dent 1986; 56:666–671.

25. Koidis PT, Schroeder K, Johnston W, Campagni W. Color consistency, plaque accumulation, and external marginal surface characteristics of the collarless metal-ceramic restoration. J Prosthet Dent 1991;65:391–400.

26. Magne P, Douglas WH. Porcelain veneers: Dentin bonding optimization and biomimetic recovery of the crown. Int J Prosthodont 1999;12:111–121.

27. Magne P, Douglas WH. Cumulative effect of successive restorative procedures on anterior crown flexure: Intact versus veneered incisors. Quintessence Int 2000;31:5–18.

28. Reeh ES, Ross GK. Tooth stiffness with composite veneers: A strain gauge and finite element evaluation. Dent Mater 1994;10:247–252.

29. Lacy AM, Wada C, Du W, Watanabe L. In vitro microleakage at the gingival margin of porcelain and resin veneers. J Prosthet Dent 1992;67:7–10.

30. Kreulen CM, Creugers NH, Meijering AC. Meta-analysis of anterior veneer restorations in clinical studies. J Dent 1998;26: 345–353.

31. Meijering AC, Creugers NH, Roeters FJ, Mulder J. Survival of three types of veneer restorations in a clinical trial: A 2.5-year interim evaluation. J Dent 1998;26: 563–568.

32. Wall JG, Reisbick MH, Johnston WM. Incisal-edge strength of porcelain laminate veneers restoring mandibular incisors. Int J Prosthodont 1992;5: 441–446.

33. Magne P, Versluis A, Douglas WH. Rationalization of incisor shape: Experimental-numerical analysis. J Prosthet Dent 1999;81:345–355.

34. Gordon JE. Strain energy and modern fracture mechanics. In: Gordon JE (ed). Structures: Or Why Things Don't Fall Down. New York: Da Capo, 1978:70–109.

35. Lin CP, Douglas WH. Structure-property relations and crack resistance at the bovine dentin-enamel junction. J Dent Res 1994;73:1072–1078.

36. Okeson JP. Temporomandibular disorders: Anatomic factors and TMD. In: Okeson JP (ed). Orofacial Pain. Chicago: Quintessence, 1996:122–123.

37. Ramfjord S, Ash MM. Anatomy and physiology of the masticatory system. Ideal occlusion. In: Ramfjord S, Ash MM (eds). Occlusion, ed 3. Philadelphia: WB Saunders, 1983:166–168.

38. Dawson PE. Anterior guidance. In: Dawson PE (ed). Evaluation, Diagnosis, and Treatment of Occlusal Problems, ed 2. St Louis: Mosby, 1989:274–297.

39. Beyron H. Optimal occlusion. Dent Clin North Am 1969;13:537–554.