A Prospective Ten-year Clinical Trial of Porcelain Veneers

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Purpose: The aim of this in vivo study was to evaluate the clinical performance of porcelain veneers after 5 and 10 years of clinical service.

Materials and Methods: A single operator placed porcelain laminates on 87 maxillary anterior teeth in 25 patients. All restorations were recalled at 5 years and 93% of the restorations at 10 years. Clinical performance was assessed in terms of esthetics, marginal integrity, retention, clinical microleakage, caries recurrence, fracture, vitality, and patient satisfaction. Failures were recorded either as "clinically unacceptable but repairable" or as "clinically unacceptable with replacement needed".

Results: Porcelain veneers maintained their esthetic appearance after 10 years of clinical service. None of the veneers were lost. The percentage of restorations that remained "clinically acceptable" (without need for intervention) significantly decreased from an average of 92% (95 CI: 90% to 94%) at 5 years to 64% (95 CI: 51% to 77%) at 10 years. Fractures of porcelain (11%) and large marginal defects (20%) were the main reason for failure. Marginal defects were especially noticed at locations where the veneer ended in an existing composite filling. At such vulnerable locations, severe marginal discoloration (19%) and caries recurrence (10%) were frequently observed. Most of the restorations that present one or more "clinically unacceptable" problems (28%) were repairable. Only 4% of the restorations needed to be replaced at the 10-year recall.

Conclusion: It was concluded that labial porcelain veneers represent a reliable, effective procedure for conservative treatment of unesthetic anterior teeth. Occlusion, preparation design, presence of composite fillings, and the adhesive used to bond veneers to tooth substrate are covariables that contribute to the clinical outcome of these restorations in the long term.

Key words: porcelain veneers, adhesion, clinical trial.

J Adhes Dent 2004; 6: 65–76. *Submitted for publication: 05.03.03; accepted for publication: 09.07.03.*

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Porcelain veneers have been a popular means of conservatively restoring unesthetic anterior teeth since the beginning of the 1980s. At that time Calamia, Simonsen, and Horn introduced special acid-etching procedures that substantially improved the long-term retention of porcelain veneers.[2,11,38] They demonstrated that the bond strength of a hydrofluoric acid-etched and silanized

veneer to the luting resin composite is routinely greater than the bond strength of the same luting resin to the etched enamel surface. As with any new procedure, the different aspects of this new approach were analyzed in many in vitro studies.[31] With the help of these results, the clinical technique has continued to be refined and the indication for porcelain veneers has gradually been extended. Most recently, restoration of crown-fractured incisors and worn-down dentitions have been proposed as new indications for porcelain veneers.[15]

A number of medium-term clinical studies have confirmed the favorable clinical performance of these restorations, as their maintenance of esthetics was excellent, patient satisfaction was high, and no adverse effects on gingival health were present.[31] Most studies reported a low failure rate (0% to 7%).[1,7,23,39] Higher failure rates (14% to 33%) were noted in other clinical trials,[6,36,37,49] probably due to some predisposing factors such as unfavorable occlusion and articulation, excessive loss of dental tissue, use of inappropriate luting agents, unprepared teeth, and partial adhesion to large exposed dentin surfaces. Nevertheless, porcelain veneers are considered more durable than direct composite veneers, on the condition that patients were adequately selected and the veneers were prepared following a meticulous clinical procedure.[31]

However, questions remain with regard to what we may expect in the long term: are they as durable as complete crowns or will there be an increased number of failures after long-term clinical service? Only a few clinical studies have reported the performance of porcelain veneers over a period of more than 9 years.[5,8,40,44] Very little information is available from standardized long-term studies that reveal clear data on the overall clinical performance of these restorations.[5] The aim of this in vivo study was to evaluate the clinical performance of porcelain veneers after 5 and 10 years of clinical service as part of a prospective clinical trial.

MATERIALS AND METHODS

In this investigation, 87 porcelain veneers were placed in 25 patients in 1990 and 1991. The porcelain veneers were prepared only on maxillary teeth (central incisors, lateral incisors, canines, and first premolars). The age of the patients varied from 19 to 69 years. All veneers were placed to improve esthetics by replacing worn and discolored composite restorations and veneers, or by correcting discolored, malformed and/or malaligned anterior teeth.[32]

The porcelain veneers were placed by a single experienced operator following a meticulous clinical procedure, which was described in detail in the previous 5-year report.[32] After preoperative procedures including prophylaxis and replacement of old composite restorations, the teeth were prepared for porcelain veneers. The amount of labial enamel reduction was between 0.3 and 0.7 mm, depending on the relative tooth position and the degree of discoloration. Proximally, the margins were extended half of the way to the interproximal contact area, while the natural contact points were retained. The shape of the cervical margin was a chamfer and was generally located equigingivally. The incisal edge was shortened and a shoulder was prepared on the palatal side over a distance of 2 to 3 mm.

All porcelain veneers were fabricated by the same technician using a feldspathic porcelain (GC Cosmotech Porcelain, GC, Tokyo, Japan) on a refractory investment material (GC Cosmotech Vest, GC). The inner side of the veneers was etched with 5% hydrofluoric acid (GC Hydrofluoric Acid, GC) for 60 s, followed by ultrasonic cleaning in a bath with distilled water for 10 min. Silanization was performed with the G-Cera Primer (GC Cosmotech Bonding Set, GC).

At the second visit, the porcelain veneers were adhesively luted under rubber-dam isolation. The preparation surface was etched with 35% phosphoric acid (Scotchgel, 3M, St Paul, MN, USA) followed by the application of Scotchbond 2 (3M) without light curing it separately. The composite luting agent – G-Cera Porcelain Veneer Bonding System (GC): 80 veneers; Porcelite (Kerr, Basel, Switzerland): 7 veneers – was applied to the inside of the porcelain veneer, which was immediately fit into place and light cured with a Visilux 2 Visible Light Curing Unit (3M) for 2 min on each side. The cemented porcelain veneers were finished by removing all excess luting composite using microfine diamonds (Esthetic Trimming Diamond set, Goldstein, Komet, Lemgo, Germany) under continuous water cooling. Finally, the roughened porcelain margins were polished using a diamond polishing paste (Komet) on a rotating rubber cup. The interproximal surfaces were finished with Sof-Lex polishing strips (3M).

Color slides were made preoperatively, after preparation, and immediately postoperatively (= baseline). All patients were recalled between April 1995 and October 1996, when the restorations were 5 to 6 years old. In addition, a 10-year recall took place between January 2001 and June 2001 with a recall rate of 93% (81 out of 87 restorations).

Evaluation Procedure

At both recalls, esthetics, marginal integrity, tooth vitality (TV), fracture rate (FR), and patient satisfaction (PS) were evaluated.

Esthetic performance was assessed clinically at chairside in terms of color match (CM) and surface roughness (SR). Marginal integrity was evaluated in terms of marginal adaptation and retention (MA/R), clinical microleakage (CMi) and caries recurrence (CR). Color slides of the restorations were made at both assessments.

Marginal adaptation and clinical microleakage were judged at four different locations of the restored tooth: mesiocervically, mid-buccocervically, distocervically, and palato-incisally.[32] All scores of marginal adaptation and microleakage at the buccocervical part of the porcelain veneer were pooled into one score at the cervical location.

The criteria were recorded by two evaluators following an index system,[45,48] which was described in detail in the 5-year report.[32] The data were provided separately by each evaluator. In case of disagreement, a consensus was reached by discussion.

Table 1 Results on color match (CM) and surface roughness (SR) (evaluation in %)

Criterion	CM		SR	
Recall	5 y (n = 87)	10 y (n = 81)	5 y (n = 87)	10 y (n = 81)
Excellent	100 (n = 87)	98 (n = 79)	100 (n = 87)	98 (n = 81)
Clinically acceptable	100 (n = 87)	98 (n = 79)	100 (n = 87)	98 (n = 81)
Clinically unaceptable	0 (n = 0)	0 (n = 0)	0 (n = 0)	0 (n = 0)
No information	0 (n = 0)	2 (n = 2)	0 (n = 0)	2 (n = 2)

n = number of restorations

Table 2 Results on patient satisfaction (PS) (evaluation in %)

Criterion	PS	
Recall	5 y (n = 25)	10 y (n = 22)
Very satisfied	80 (n = 20)	59 (n = 13)
Satisfied	20 (n = 5)	32 (n = 7)
No information	0 (n = 0)	9 (n = 2)

n = number of patients

Table 3 Results on fracture rate (FR) (evaluation in %)

Criterion	FR	
Recall	5 y (n = 87)	10 y (n = 81)
Clinically acceptable		
Fracture line	2 (n = 2)	21 (n = 17)
Chipping	1 (n = 1)	2 (n = 2)
Clinically unacceptable		
Small bulk fracture (repairable)	0 (n = 0)	9 (n = 7)
Large bulk fracture (irreparable)	1 (n = 1)	2 (n = 2)

n = number of restorations

The restorations were divided into "clinically acceptable" restorations and "clinically unacceptable" restorations or failures. In addition, the failures were recorded as "clinically unacceptable but repairable" and as "clinically unacceptable with replacement needed".

Statistical Analysis

Since multiple restorations per patient were placed and these restorations are possibly correlated, the width of a classical 95% confidence interval for the proportion "acceptable" (vs not acceptable but repairable, and not acceptable and replacement needed) would be an underestimation. Therefore, simulations were used to compute the 95% confidence interval (95 CI) for the results after 5 years and after 10 years separately. All simulations were based on a random intercepts model (thus with patient as random effect). In the simulations, samples of 25 patients were generated using the estimates of the random intercepts and taking into account the variability of these estimates. The parameters of the random intercepts model were estimated with the SAS procedure NLMIXED (Versions 8.01). Simulations were also performed using SAS.

RESULTS

Esthetics

At the 10-year recall, the esthetic parameters color match (CM) and surface roughness (SR) were rated as optimal for all veneers (Table 1). No information was available about two restorations as they were replaced by a crown. Regarding patient satisfaction (PS), 13 out of 22 patients were still very satisfied with the esthetic result of the porcelain veneers after 10 years, and 7 patients complained about minor esthetic problems (Table 2).

Fracture Rate

The fracture rate (FR) increased substantially from 4% at the 5-year recall to 34% at the 10-year recall (Table 3). Most fractures (23%) were clinically acceptable: two veneers showed a small incisal porcelain chipping, and a visible fracture line was observed in 21% of the restorations on the palatal or the buccal side. In total, 11% of the fractures were clinically unacceptable at the 10-year recall. Nine percent of the restorations showed a small palatal fracture and were repaired using composite. Two veneers (2%) were replaced by a crown, because a large bulk fracture of the veneer occurred after 7 years in one case and 8 in the other.

Marginal Integrity

Marginal adaptation and retention

No restoration was lost after 10 years (R_4) (Table 4). The percentage of restorations with an excellent marginal adaptation along the entire outline of the porcelain veneer (R_1) decreased further from 14% at the 5-year recall to 4% at the 10-year recall (Table 5). The number of small de-

Table 4 Results on marginal adaptation and retention (MA/R) (evaluation in %)

Criterion	MA/R					
Location	Cervical total		Palato-incisal		Total	
Recall	5 y (n = 87)	10 y (n = 81)	5 y (n = 87)	10 y (n = 81)	5 y (n = 87)	10 y (n = 81)
R_1	46 (n = 40)	11 (n = 9)	36 (n = 31)	9 (n = 7)	14 (n = 12)	4 (n = 3)
R_2	54 (n = 47)	77 (n = 62)	63 (n = 55)	78 (n = 63)	86 (n = 75)	74 (n = 60)
R_3	0 (n = 0)	10 (n = 8)	0 (n = 0)	11 (n = 9)	0 (n = 0)	20 (n = 16)
R_4	0 (n = 0)	0 (n = 0)	0 (n = 0)	0 (n = 0)	0 (n = 0)	0 (n = 0)
No information	0 (n = 0)	2 (n = 2)	0 (n = 0)	2 (n = 2)	0 (n = 0)	2 (n = 2)

n = number of restorations; R_1 = no marginal defect; R_2 = slight marginal defect; R_3 = severe marginal defect; R_4 = loss of restoration

Table 5 Combined results on marginal adaptation and retention (MA/R) (evalution in %)

Criterion	MA/R	
Recall	5 y (n = 87)	10 y (n = 81)
Excellent (R_1)	14 (n = 12)	4 (n = 3)
Clinically acceptable (R_{12})	99 (n = 86)	78 (n = 63)
Clinically unacceptable (R_{34})	1 (n = 1)	20 (n = 16)
No information	0 (n = 0)	2 (n = 2)

n = number of restorations, R_1 = no marginal defect; R_2 = slight marginal defect; R_3 = severe marginal defect; R_4 = loss of restoration; R_{12} = clinically acceptable marginal adaptation; R_{34} = clinically unacceptable marginal adaptation

fects (R_2) at the cervical margin (5 yrs: 54%; 10 yrs: 77%) and at the palato-incisal margin (5 yrs: 63%; 10 yrs: 78%) increased from 5 to 10 years (Table 4). A large unacceptable marginal defect (R_3) was noted in 16 veneers out of 81 (20%) (Tables 4 and 5).

Clinical microleakage

The number of restorations showing clinical microleakage (CMi_2 + CMi_3) increased dramatically from 5 years (26%) to 10 years (65%) (Table 6). In 19% (15) of the restorations, a clinically unacceptable marginal discoloration (CMi_3) was observed at the 10-year recall (Tables 6 and 7). At both recalls, a higher percentage of clinical microleakage was noted at the cervical margin than at the palato-incisal margin (Table 6).

Caries Recurrence

At the 10-year recall, caries in contact with the margin of the veneer was recorded more frequently (8 restorations) compared with the 5-year recall (2 restorations) (Table 8). Most carious lesions (7) were observed where veneers crossed an existing (interproximal) composite restoration, in particular at the transition from tooth to porcelain veneer to underlying composite restoration. Only one carious lesion was present at the cervical interface of tooth/luting composite/porcelain.

Tooth Vitality

Pulpal irritation occurred in two veneered teeth with deep interproximal composite fillings after approximately 3 years. Another restored tooth with a large composite filling and caries recurrence showed a negative pulpal response at the 10-year recall (Table 9). All these teeth needed endodontic treatment. During this treatment, one tooth fractured and needed restoration with a crown.

Combined Results

Statistical analysis revealed that the percentage of veneers that remained clinically acceptable (without any need for intervention) decreased from an average of 92% (95 CI: 90% to 94%) at 5 years to 64% (95 CI: 51% to 77%) at 10 years. Large marginal defects (20%) and fractures (11%) were the main reasons for failure. Severe marginal discoloration (19%) and caries recurrence (10%) were especially noticed at locations where the veneer ended in an existing composite filling or in dentin. Nevertheless, most of the veneers (28%) that presented one or more clinically unacceptable problems were repairable. Only 4% of the veneers needed to be replaced at the 10-year recall (Table 10).

DISCUSSION

Today, porcelain veneers are no longer in the experimental stage; they have gained respect as a durable and reliable restorative treatment method. Patients and dentists are enthusiastic about their superb esthetic properties and the conservative tooth preparation. Their durability has been confirmed by different medium-term and a few long-term clinical studies. A review of these clinical studies with their respective descriptive statistics and failure rates is summarized in Table 11. The failure rate varied widely among these studies (0% to 33%). A meta-analysis of clinical studies involving anterior veneer restorations revealed that the study results can hardly be compared due to insufficient standardization in modes of reporting.[13] Study design, patient selection, and clinical procedure also differed significantly among those clinical trials. Nevertheless, it became clear from these clinical studies that specific conditions fa-

Table 6 Results on clinical microleakage (CMi) (evaluation in %)

Criterion	CMi					
Location	Cervical total		Palato-incisal		Total	
Recall	5 y (n = 87)	10 y (n = 81)	5 y (n = 87)	10 y (n = 81)	5 y (n = 87)	10 y (n = 81)
CMi_1	78 (n = 68)	43 (n = 35)	90 (n = 78)	60 (n = 48)	74 (n = 64)	33 (n = 27)
CMi_2	22 (n = 19)	40 (n = 32)	9 (n = 8)	33 (n = 27)	25 (n = 22)	46 (n = 37)
CMi_3	0 (n = 0)	15 (n = 12)	1 (n = 1)	5 (n = 4)	1 (n = 1)	19 (n = 15)
No information	0 (n = 0)	2 (n = 2)	0 (n = 0)	2 (n = 2)	0 (n = 0)	2 (n = 2)

n= number of restorations; CMi_1= no discoloration; CMi_2= superficial discoloration; CMi_3= deep discoloration

Table 7 Combined results on clinical microleakage (CMi) (evaluation in %)

Criterion	CMi	
Recall	5 y (n = 87)	10 y (n = 81)
Excellent (CMi_1)	74 (n = 85)	33 (n = 27)
Clinically acceptable (CMi_{12})	99 (n = 86)	79 (n = 64)
Clinically unacceptable (CMi_3)	1 (n = 1)	19 (n = 15)
No information	0 (n = 0)	2 (n = 2)

n = number of restorations; CMi_1 = no discoloration; CMi_2 = superficial discoloration; CMi_3 = deep discoloration (clinically unacceptable); CMi_{12} = clinically acceptable marginal discoloration

Table 8 Results on caries recurrence (CR) (evaluation in number of restorations)

Criterion	CR	
Recall	5 y (n = 87)	10 y (n = 81)
Caries in contact with margin	2	8
Caries at interface tooth/ porcelain veneer/underlying composite restoration	2	7
Caries at interface tooth/ porcelain veneer	0	1

n = number of restorations

Table 9 Results on tooth vitality (TV) (evaluation in %)

Criterion	TV	
Recall	5 y (n = 87)	10 y (n = 81)
Clinically acceptable	98 (n = 85)	96 (n = 78)
Clinically unacceptable (*became nonvital)*	2 (n = 2)	4 (n = 3)

n = number of restorations

Table 10 Combined results on clinical performance (evaluation in %)

Criterion	Clinical performance	
Recall	5 y (n = 87)	10 y (n = 81)
Excellent	14 (n = 12)	4 (n = 3)
Clinically acceptable	93 (n = 81)	68 (n = 55)
95 CI	92 (90 – 94)	64 (51 – 77)
Clinically unacceptable	7 (n = 6)	32 (n = 26)
• Repair	6 (n = 5)	28 (n = 23)
• Replacement	1 (n = 1)	4 (n = 3)

n = number of restorations

vor porcelain veneer failure or success,[6,8,36,49] and some of these situations will become more obvious with aging.[5] This in vivo study evaluated the overall clinical performance of porcelain veneers after 10 years of clinical service in comparison to the 5-year recall.[32]

Regarding esthetics, the color match and surface smoothness remained unchanged after a period of 10 years (Fig 1). Our results agree with those reported in all other clinical trials.[5,7,23,40] Some authors noticed a small but acceptable color change when a single nonvital discolored tooth was masked with a veneer.[5,23] Likewise, when nonvital teeth were veneered in our study, three patients were not completely satisfied with the esthetic result. The same observation was made at the 5-year recall.[32] In addition, four patients complained of minor esthetic problems where marginal discoloration and/or gingival recession were noticeable. An increased tendency for gingival recession at the veneered teeth was already noticed after 5 years,[28] but became more obvious at the 10-year recall. Dumfahrt and Schäffer[5] described a similar phenomenon in a 10-year retrospective study, where at 10 years gingival recession was detected in 31% of the teeth restored

Table 11 Descriptive statistics of medium-term and long-term clinical trials involving porcelain veneers

Author	Number of veneers	Number of patients	Porcelain/adhesive system	Type of preparation	Observation period	Evaluation criteria*	Failure rate
Van Gogswaardt et al [44]	258	57	NS	NS	9 y	Ryge criteria (NS)	6%
Strassler and Weiner [40]	183	33	Cerinate (Den- Mat)/ Ultrabond (Den-Mat)	No preparation Conventional (no incisal overlap)	12-190 months	1,4,5,6,7,8 (modified USPHS† criteria)	6%
Friedman [8]	3500	NS	NS	NS	1-15 y	5,7,8	7%
Dumfahrt and Schäffer [5]	191	56	Optec HSP/ (Jeneric/Pentron) Syntac (Vivadent) Optibond (Kerr)/ Dual Cement (Coltène), Variolink (Vivadent), Indirect Porcelain Bonding Kit (3M)	Conventional (no incisal overlap) Incisal overlap	14-60 months 61-127 months	1,2,4,5,7,8, 10,11	4%
Fradeani [7]	83	21	IPS Empress/Syntac (Vivadent)	Incisal overlap	1-6 y	1,3,4,5,6,7,8 (modified USPHS criteria)	1%
Magne et al [23]	48	16	Kreation/Herculite Incisal LT (Kerr)	Incisal overlap	3-7 y	1,4,5,6,7,8,9, 10,11	0%
Sieweke et al [37]	36 (palatal veneers)	17	IPSEmpress/Duozem	Palatal preparation	1-6.5 y	7,8	24%
Aristidis and Dimitra [1]	186	61	Ceramco/Variolink II (Vivadent)	Incisal overlap	5 y	1,2,4,5,6,7,8, 10,11	1,6%
Strassler and Weiner [39]	115	21	Cerinate (Den-Mat)/ Ultrabond (Den-Mat)	No preparation Conventional (no incisal overlap)	7-10 y	1,4,5,6,7,8 (modified USPHS criteria	7%
Peumans et al [32]	87	25	GC Cosmotech Porcelain/GC Cosmotech Bonding Set (GC) + Scotchbond 2 (3M)	Incisal overlap	5-6 y	1,2,4,5,6,7,8, 10,11	7%
Walls [49]	54	12	Fiber-reinforced porcelain (NS)/ Heliolink (Vivadent) + Gluma (Bayer)	Special preparation for worn teeth	5 y	5,7,8,10	14%
Shaini et al [36]	372	102	Vitadur N (Vita)/ Heliobond (Vivadent)	No preparation Conventional (no incisal overlap)	6.5 y	Failures – repairable – replacement	9% 32,8%
Dunne and Millar [6]	315	96	NS	Conventional (no incisal overlap) Incisal overlap	5 y	Failures – repairable – replacement	8% 11%

Evaluation criteria*: color (1), surface texture (2), wear (3), marginal adaptation (4), marginal discoloration (5), caries (6), fracture (7), retention (8), postoperative sensitivity (9), gingival response (10), patient satisfaction (11), failures (12).
†USPHS=US Public Health Service; NS= Not specified

with porcelain veneers. The occurrence of gingival retraction was significantly related to the age of the porcelain veneer and to the equigingival or subgingival location of the restoration margin. In addition, gingival recession was noticed on veneered as well as on nonrestored teeth, as was also the case in the present study. Indeed, a longitudinal clinical analysis demonstrated that in subjects with a high standard of oral hygiene, buccal recessions oc-

Fig 1a Preoperative view of old composite veneers on maxillary anterior teeth.

Fig 1b Baseline, porcelain-veneers on 14–23.

Fig 1c Porcelain veneers at 5-year recall.

Fig 1d 10-year recall, porcelain veneers still show good esthetics.

Fig 1e 10-year recall, slight marginal discoloration and gingival recession on left canine.

Fig 1f 10-year recall. Marginal discoloration and wearing out of the luting composite at the palatal margins and fracture line at the palatal side of the left lateral incisor.

curred frequently, and that the proportion of subjects with recession increased with age.[35] This gingival recession can influence the esthetic outcome of the restoration, especially when a dark discoloration is masked. In spite of these minor esthetic shortcomings, all patients were still satisfied with the esthetic outcome of the veneers at the 10-year recall. A high patient acceptance was noticed in other clinical trials as well.[5,23] One can therefore conclude that porcelain veneers exhibit a good esthetic performance in the long term. However, the presence of marginal discoloration and gingival recession can influence the overall esthetic outcome of the veneered teeth.

A remarkable observation in this clinical study was the dramatic increase in the number of fractures from 5 years (4%) to 10 years (34%). Most fractures (23%) were clinically acceptable. Two restorations showed a small fracture

Fig 2a Preoperative view of old composite veneers on maxillary central incisors.

Fig 2b Porcelain veneers on 11 and 21 at baseline.

Fig 2c Porcelain veneers at 5-year recall.

Fig 2d 5-year recall. Heavy occlusal contact was noted on the distopalatal side of the right central incisor.

Fig 2e 10-year recall. A fracture line was noticed at the site of heavy occlusal loading.

Fig 2f 10-year recall. Fracture line (of Fig 2e) extends to facial side.

of incisal porcelain and were recontoured with a superfine diamond. These incisal chippings, attributed to excessive loading, were observed with the same frequency in other clinical studies.[5,7,12,23,36] In addition, fracture lines were noticed in 21% of the restorations. This phenomenon of crack formation was described in detail by Magne et al,[23] who reported fracture lines in 12% of the porcelain restorations after 4.5 years of clinical functioning. The crack lines can be caused by shrinkage of the luting composite, and by thermal and mechanical loading. To prevent the occurrence of crack lines, a controlled and uniform tooth reduction is important. In addition, a minimal and homogeneous thickness of ceramic combined with a minimal thickness of luting composite and a favorable ratio of porcelain thickness to luting composite thickness (> 3) will minimize the occurrence of crack formation.[22,24]

Fig 3 A small bulk fracture of porcelain occurred at the palatal side after 10 years due to a shortcoming in preparation form in combination with heavy occlusal loading.

Fig 4 Fracture line at the buccal side of both premolars. The premolars and also the front teeth were veneered in order to mask the tetracycline staining. These fracture lines were mostly caused through abfraction. A gingival recession was also noted at the 10-year recall. A dark gingival zone became visible.

In the present study, the porcelain was slightly thinner at the palatal side because a preparation with a long palato-incisal overlap was made. This thin extension did in fact tend to show more cracks that extended from the palatal chamfer to the facial surface of the ceramic veneer[3,17] (Fig 2). Consequently, the fracture lines grew due to repeated heavy mechanical loading and eventually led to a large porcelain fracture in this region. This type of clinically unacceptable fracture on the palatal side occurred in 7 restorations in the present study (Fig 3). These palatal defects did not reduce the esthetics of the restorations and were easily repaired with resin composite. To diminish the occurrence of crack lines and fractures on the palatal side, a mini-chamfer or butt-joint preparation is nowadays advocated. This preparation margin provides the restoration with a stronger bulk of porcelain, as was demonstrated in vitro by Castelnuovo et al[3] and by Magne et al.[17]

Facial and cervical locations are also critical areas of the restoration in terms of crack lines, if the ceramic was not overcontoured as a compensation for insufficient space.[24] In this study, the fracture lines in the buccocervical region most likely arose from abfraction,[14] a phenomenon that was also observed by Friedman[8] and Dumfahrt and Schäffer[5] (Fig 4). During palatal loading, Troedson et al[41] measured in vitro high shear stress in the adhesive layer under porcelain veneers that lacked adhesion in the buccocervical periphery. These high stresses can lead to porcelain fracture in this region and finally to debonding of the facing. This phenomenon will occur more rapidly when dentin is exposed in the cervical region and a third generation dentin adhesive – such as Scotchbond 2 in the present study – was applied, because this bond to dentin is obviously weaker than the bond to enamel.[46,47] Modern adhesive systems in current use should certainly yield better results in this regard.[4,16,46] Nevertheless, all authors advise an intra-enamel preparation if possible, or at least a preparation where all margins end in enamel. Intact enamel remains the substrate to which etched porcelain veneer restorations can most reliably be bonded. Controlled preparation techniques using silicon indices, made on an additive diagnostic waxup, are imperative.[18]

Finally, two restorations in two patients showed a large bulk fracture after 7 and 8 years, respectively, and were replaced by a crown. Both veneers were placed on discolored, endodontically treated teeth with large composite fillings. The inferior adhesion to the large composite surface and a large exposed dentin surface were probably the most important reasons for these failures. In the literature, some controversy exists concerning the fact that porcelain veneers bonded to nonvital teeth will fail more easily. Although some clinical studies found an increased failure risk,[26,36] other in vitro studies have shown that endodontically treated, veneered incisors behaved like endodontically treated, nonveneered teeth.[10,20] The latter authors stated that, except in cases of endodontically treated teeth with severe loss of tooth substance as in the present study, there is currently no evidence that contraindicates veneering nonvital teeth.

The percentage of clinically unacceptable fractures varied widely among the different clinical studies (Magne et al:[23] 0%; Kihn and Barnes:[12] 0%; Fradeani:[7] 2.5%; Dumfahrt and Schäffer:[5] 7%; Walls:[49] 14%; Sieweke et al:[37] 22%). Predisposing factors for the occurrence of fractures were almost the same as in our clinical study, such as partial adhesion to a dentin surface, presence of large composite fillings, bonding to endodontically treated teeth, and heavy mechanical loading during occlusion and articulation.

To summarize, the occurrence of fractures can be minimized by a careful selection of the patient, a controlled and uniform tooth reduction with palatal mini-chamfer or butt-joint, a minimal and homogeneous thickness of ceramic, a minimal thickness of luting composite, and a favorable ratio of porcelain thickness to luting composite thickness (> 3). In addition, the application of a modern

Fig 5 10-year result of veneered 11, 12 and 21. Severe marginal discoloration was noted at the cervical dentin margin of both central incisors and at the mesiocervical margin of the right lateral incisor at the interfaces of tooth/underlying composite restoration/porcelain veneer.

Fig 6 10-year result of veneered anterior maxillary teeth (13-23). In this patient with high caries activity, caries was present at the interfaces of tooth/underlying composite restoration/porcelain veneer distocervically on the left central incisor. A strong marginal discoloration was also noticed at the cervical margin of the veneered canine.

adhesive and careful evaluation of occlusion and articulation is desirable.

In spite of the high percentage of fractures in this study, the retention of porcelain veneers was still excellent after 10 years. A high retention rate was also noted in other long-term clinical studies.[5,40] These clinical results confirm that porcelain veneers are strongly bonded to the underlying tooth surface, which has also been clearly demonstrated in vitro.[16,33]

The presence of composite fillings (present in 70% of the porcelain veneers in our study) did not seem to influence the retention of veneers, even after 10 years. This can in part be explained by the in vitro results of Magne et al,[19] who showed that the original tooth compliance in fractured teeth was almost restored when composite was used to replace the missing dentin, with the porcelain acting only as a facial and incisal enamel substitute. Although the presence of composite fillings did not increase the loss of veneers in this study, they had a negative influence on the overall clinical performance, as will be discussed below.

The marginal quality of the veneers obviously decreased with increasing age of the restoration. Only 4% of the veneers showed a perfect margin over the entire outline at the 10-year recall. This low percentage was attributed to a further increase in the number of small marginal defects (R_2) during the last 5 years. This increase was more pronounced at the buccocervical margins than at the palato-incisal margins. Consequently, there was almost no difference anymore in the number of small defects between both cervical and incisal locations at the 10-year recall. Thus, the wear of the luting agent seems to stabilize when the washing out has reached a certain depth. This phenomenon was described in clinical studies for ceramic inlays as well.[9,34,42] Although earlier in vitro and in vivo studies[31,42,43] have shown that degradation of the luting cement by wear could be the weak link in the porcelain veneer system, it still did not increase the number of failures after 10 years of clinical functioning.

Sixteen out of 81 restorations presented a clinically unacceptably large marginal defect. One defect with a caries lesion was observed at the cervical interface porcelain veneer/tooth in a patient with suboptimal oral hygiene. Moreover, the restorations with a palatal fracture (7) were also evaluated as having a large marginal defect. Finally, most large marginal defects (8) were noticed in veneers that ended in an existing composite filling.

Several explanations can be given for the negative influence of the underlying composite restorations on the marginal behavior of porcelain veneers. First, composite restorations have a limited longevity varying from 5 to 10 years,[25,27,29,30] and this is due to some shortcomings in physicomechanical properties of the resin composite, such as polymerization shrinkage, elasticity, high thermal expansion coefficient, and limited wear resistance. Second, the bond of the porcelain facing to the composite restoration is inferior compared with bonding to enamel or dentin, as this bonding is based on delayed resin-resin bonding and fails more easily. Finally, the high thermal expansion of (interproximal) composites has a negative influence on (interproximal) marginal adaptation.[21] During severe temperature changes, contraction and expansion of the composite causes tensile and compressive stresses at the porcelain veneer margins with loss of bonding, deformation of the veneer margins, and formation of cracks as a consequence. The thermal stresses can be minimized by partial or total wrapping of pre-existing composite restorations, because in these medium-length and long interdental wraparounds, part of the pre-existing composite bulk is replaced by the extension of the ceramic.

At the vulnerable interfaces of porcelain/tooth/underlying composite, a strong marginal discoloration was noted in 12 restorations (Fig 5). In half of these restorations,

caries was present at this location; five of these veneered teeth in one caries-active patient showed caries recurrence (Fig 6). Therefore, veneers should not be placed in patients with high caries activity. Severe marginal discoloration was also observed at the cervical dentin margin of 5 restorations. As was already discussed at the 5-year recall, the third generation dentin adhesive Scotchbond 2 was not able to prevent microleakage at the dentin margins.[32] This marginal discoloration became even more apparent with the aging of the restorations.

The total number of restorations with microleakage increased greatly from 25% at the 5-year recall to 64% at the 10-year recall. A less obvious increase in microleakage was observed in other clinical studies (Dumfahrt and Schäffer:[5] 18%; Fradeani:[7] 7%; Magne et al:[23] 7%; Strassler and Weiner:[40] 16%; Walls:[49] 28%). Improved results are expected when a contemporary modern adhesive is used and when veneers have a partial wraparound in the presence of interproximal composite restorations.

The failure rate, which finally determines the durability of porcelain veneers, increased significantly from 7% at the 5-year recall to 32% at the 10-year recall. This percentage was lower in most clinical trials (Table 11). Only Shaini et al [36] reported a failure rate of 33% after 6.5 years, but this was due to serious shortcomings in the clinical procedure.

Both the technique of porcelain veneers and adhesive techniques have improved during the last 5 years, leading to more durable veneers. However, some of these refinements – such as corrections in tooth preparation and the use of more reliable adhesives – were not employed in this clinical study. Therefore, it may not be necessary to interpret the high failure rate in the present study overly negatively. The failures were subdivided in repairable and irreparable failures (= total failures). The total failure rate at 10 years was low, only 4%. These total failures were present in veneered teeth with a large amount of lost tooth tissue. It may therefore be concluded that porcelain veneers are not indicated in such teeth.

The other 28% repairable failures represent palatal fractures, large marginal defects at the interfaces of tooth/underlying composite/porcelain, and severe microleakage. They must be considered as complications with a positive outcome because repair of these restorations can be made with simple means at minimal costs.

CONCLUSION

Summarizing and concluding the results of this investigation, it can be stated that labial porcelain veneers represent a reliable, effective procedure for conservative treatment of unesthetic anterior teeth in the long term. The maintenance of esthetics was good, patient satisfaction was high, and the retention rate was still excellent after 10 years. In addition, caries recurrence at the tooth/porcelain veneer interface was limited. The number of irreparable failures was low at 10 years. Factors such as occlusion, preparation design, presence of composite fillings, and the adhesive used were covariables that contributed to the ultimate clinical outcome of porcelain veneers in the long term.

ACKNOWLEDGMENTS

The authors would like to acknowledge the help and expertise of GC International (Leuven, Belgium) and specifically of Mr. Paul Delee, who took care of the technical part of the restorations in this study.

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Clinical relevance: If carefully applied and given a restrictive indication, bonded ceramic veneers are a very reliable type of esthetic restoration in the anterior segment. In most cases, small problems can be successfully repaired, which prevents the replacement of the restoration. Due to its conservation of sound tooth structures, one should prefer veneers over crowns, if the clinical situation allows their placement.