Porcelain veneers: a review of the literature

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Received 15 April 1999; received in revised form 25 June 1999; accepted 10 September 1999

Abstract

Objectives: Porcelain veneers are steadily increasing in popularity among today’s dental practitioners for conservative restoration of unaesthetic anterior teeth. As with any new procedure, in vitro and in vivo investigations are required to assess the ultimate clinical efficacy of these restorations. The current literature was therefore reviewed in search for the most important parameters determining the long-term success of porcelain veneers.

Data sources: Laboratory studies focusing on parameters in prediction of the clinical efficacy of porcelain veneers such as the tooth preparation for porcelain veneers, the selection and type of the adhesive system, the quality of marginal adaptation, the resistance against microleakage, the periodontal response, and the aesthetic characteristics of the restorations have been reviewed. The clinical relevance of these parameters was then determined by reviewing the results of short and medium to long-term in vivo studies involving porcelain veneers performed during the last 10 years.

Conclusions: The adhesive porcelain veneer complex has been proven to be a very strong complex in vitro and in vivo. An optimal bonded restoration was achieved especially if the preparation was located completely in enamel, if correct adhesive treatment procedures were carried out and if a suitable luting composite was selected. The maintenance of aesthetics of porcelain veneers in the medium to long term was excellent, patient satisfaction was high and porcelain veneers had no adverse effects on gingival health in patients with an optimal oral hygiene. Major shortcomings of the porcelain veneer system were described as a relatively large marginal discrepancy, and an insufficient wear resistance of the luting composite. Although these shortcomings had no direct impact on the clinical success of porcelain veneers in the medium term, their influence on the overall clinical performance in the long term is still unknown and therefore needs further study. © 2000 Elsevier Science Ltd. All rights reserved.

Keywords: Porcelain veneers; Adhesion; Clinical effectiveness; Laboratory performance; Literature review

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1. Introduction

The patients’ demand for treatment of unaesthetic anterior teeth is steadily growing. Accordingly, several treatment options have been proposed to restore the aesthetic appearance of the dentition. For many years, the most predictable and durable aesthetic correction of anterior teeth has been achieved by the preparation of full crowns. However, this approach is undoubtedly most invasive with substantial removal of large amounts of sound tooth substance and possible adverse effects on adjacent pulp and periodontal tissues. The great progress in bonding capability to both enamel and dentine made with the introduction of multi-step total-etch adhesive systems [1–3], along with the development of high-performance and more universally applicable small-particle hybrid resin composites has led to more conservative restorative adhesive techniques to deal with unaesthetic tooth appearance. Resin composite veneers can be used to mask tooth discolorations and/or to correct unaesthetic tooth forms and/or positions. However, such restorations still suffer from a limited longevity, because resin composites remain susceptible to discoloration, wear and marginal fractures, reducing thereby the aesthetic result in the long term [4,5]. In search for more durable aesthetics, porcelain veneers have been introduced during the last decade. Glazed porcelain veneers were proposed to be durable anterior restorations with superior aesthetics. The idea of porcelain veneers is not a new one. In 1938, Dr Charles Pincus [6] described a technique in which porcelain veneers were retained by a denture adhesive during cinematic filming. The fragile restorations had to be removed after filming because no adhesive system existed at that time to permanently attach them. Simonsen and Calamia [7] as well as Horn [8] reactivated the interest in porcelain veneers by introducing special acid-etching procedures that substantially improved the long-term porcelain veneer retention. They demonstrated that the bond strength of an hydrofluoric acid-etched and silanated veneer to the luting resin composite is routi-
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silanated veneer to the luting resin composite is routi-

nely greater than the bond strength of the same luting resin to the etched enamel surface [9]. From the moment porcelain veneers could be adhesively luted, the clinical and laboratory techniques have continued to be refined. As with any new procedure, in vitro studies are required to analyse the different aspects of this new system, which are important for clinical functioning. And finally, in vivo studies are needed to assess the ultimate clinical efficacy of these restorations. Therefore, laboratory studies focusing on the most important parameters in prediction of the clinical efficacy of porcelain veneers have been reviewed. The clinical relevance of these parameters was then determined by reviewing the results of short and medium to long-term in vivo studies involving porcelain veneers performed during the last 10 years.

1.1. The adhesion complex: tooth/luting composite/porcelain

The porcelain veneer technique includes the bonding of a thin porcelain laminate to the tooth surface using adhesive techniques and a luting composite in order to change the colour, form and/or position of anterior teeth. The success of the porcelain veneer is greatly determined by the strength and durability of the formed bond between the three different components of the bonded veneer complex, as there are the tooth surface, the luting composite and the porcelain veneer.

1.1.1. Tooth surface

Concepts regarding the preparation of teeth for porcelain veneers have changed over the past few years. Although early concepts suggested minimal or no tooth preparation [8,10–13], current beliefs support removal of varying amounts of tooth structure [10,14–19]. Enamel reduction is required to improve the bond strength of the resin composite to the tooth surface [20–22]. Doing so, the aprismatic top surface of mature unpre-
pared enamel, which is known to offer only a minor reten-
tion capacity, is removed. In addition, care must be taken to maintain the preparation completely in enamel to realise an optimal bond with the porcelain veneer [23]. Although the results of the newest generation dentin adhesive systems are very promising, the bond strength of porcelain bonded to enamel is still superior when compared with the bond strength of porcelain bonded to dentin [24,25].

The vast majority of teeth receiving porcelain laminate veneers should have some enamel removal, usually approxi-
amately 0.5 mm, which allows for the minimal thickness of porcelain. Christensen [26] states that 0.75 mm is the opti-
mum amount of enamel that should be removed. According to Ferrari et al. [27], however, the extent and thickness of enamel in the gingival area of anterior teeth does not permit a reduction of 0.5 mm without encroaching upon the dentine. In addition, Natress et al. [28] found that in case of freehand preparation, the proximal and cervical enamel was reduced more than 0.5 mm in the vast majority of cases with exposure of dentine in most teeth.

If dentine is exposed, protection is recommended for the period between preparation and cementation in order to prevent post-operative sensitivity and bacterial invasion [29,30]. The temporary materials (resin composite or acrylic resin) currently in use only partially seal the surface [31,32]. More effectively, the exposed dentine can be protected by means of a primer, which is a hydrophilic reactive monomer in an organic solvent [33,34]. The use of these primers or desensitisers after preparation seems not to deteriorate adhe-
sion to dentine when the exposed dentine surface is adequately re-treated at the final appointment prior to the actual cementa-
tion [35]. Paul and Schärer [36] even proposed the application of the dentin bonding agent immediately after completion of tooth preparation. This new dentin bonding agent application
technique may prevent the development of bacterial leakage and dentin sensitivity during the temporary phase, and the technique is associated with improved bond strength in vitro. If temporary resin veneers must be placed because of aesthetic and/or phonetic reasons, it is indicated to use an eugenol free temporary cement in order to maintain the original bond strength [37]. Alternatively temporary veneers may be constructed in composite, held in place by a small area of etched enamel [14,17].

Regarding the incisal preparation, three basic types of preparation have been described namely, the window or intra-enamel preparation, the overlapped incisal edge preparation and the feathered incisal preparation. Several authors favoured the overlapped incisal preparation [16,17,26]. With this type of incisal preparation, the dental technician has more control on the aesthetic characteristics of the incisal part of the porcelain veneer. In addition, this preparation will make the restoration more resistant to incisal fractures. Highton et al. [38] confirmed this latter statement in vitro using a two-dimensional photo-elastic stress analysis. This type of preparation distributed the occlusal load over a wider surface area and, consequently, reduced stress concentration within the veneer. On the contrary, an in vitro study by Hui et al. [39] and Gilde et al. [40] demonstrated that an overlap porcelain veneer design will transmit maximum stress on the veneer and increases the risk of cohesive fracture. A window design prepared entirely into enamel withstood axial stress most favourably in this investigation. They concluded that where strength is an important requisite, the most conservative type of veneer, namely the window preparation, was the design of choice. However, in the clinical study of Meijering et al. [41] no relation was seen between survival and incisal preparation design (no incisal overlap versus incisal overlap) for both indirect resin composite and porcelain veneers after 2.5 years of clinical functioning. Further in vivo studies have to point out if a similar result would be noticed in the long term.

1.1.2. Porcelain veneer

Veneers are mainly fabricated from conventional low fusing feldspathic porcelain. Two methods for fabrication of these porcelain veneers have been described: the platinum foil technique [8,11,14,42] and the refractory die technique [14]. At present, the refractory die technique is preferred to the platinum foil technique in most laboratories [43].

By etching the inner side of the porcelain veneer with hydrofluoric acid and subsequently silanizing the etched surface, the bond strength of a luting composite to the etched porcelain surface has been measured to be higher than the bond strength of a luting composite to etched enamel and even exceeding the cohesive strength of the porcelain itself [9,22,44–47]. Etching the inner side of the porcelain veneer with hydrofluoric acid creates a retentive etch pattern. SEM of the etched porcelain surface showed an amorphous micro-structure with numerous porosities [44,47–50] (Fig. 1). These micro-porosities increase the surface area for bonding and lead to a micro-mechanical interlocking of the resin composite. Several factors like the etching time, concentration of the etching liquid, fabrication method of the porcelain restoration [7,44], and type of porcelain [51,52] determine the micro-morphology of the etch pattern and consequently the bond strength of the resin composite to the etched porcelain.

In addition to micro-porosities, micro-cracks were observed that grow when the etching time increases [49]. These cracks can act as sources of crack initiation and slightly, although not significantly, decrease the flexural strength of the etched porcelain. Weakening of the
Ultrasound cleaning of etched porcelain in 95% alcohol, acetone or distilled water is indicated to remove all residual acid and dissolved debris from the surface. Inadequate rinsing after etching the porcelain surface may leave remineralised salts, which can be recognised as a white residue or deposit [55]. Some authors [50,56] studied the etch patterns of hydrofluoric acid on feldspathic porcelain with SEM and concluded that the best surface, in terms of penetrability, was obtained by immersion of the etched porcelain in an ultrasonic bath. Aida et al. [57], however, observed no significant differences in surface morphology and bond strength between etched (5% GC Hydrofluoric Acid, GC Corp., Tokyo, Japan) feldspathic porcelain with and without ultrasonic cleaning.

Silanization of etched porcelain with a bi-functional coupling agent provides a chemical link between the luting resin composite and porcelain. A silane group at one end chemically bonds to the hydrolysed silicon dioxide at the ceramic surface, and a methacrylate group at the other end copolymerises with the adhesive resin. Single-component systems contain silane in alcohol or acetone and require prior acidification of the ceramic surface with hydrofluoric acid to activate the chemical reaction. With two-component silane solutions, the silane is mixed with an aqueous acid solution to hydrolyse the silane, so that it can react directly with the ceramic surface. If not used within several hours, silane will polymerise to an unreactive polysiloxane [58]. Several authors reported differences in bond strength dependent on the silane treatment used [45,46,51,56]. In addition, heating of the silane-coated porcelain to 100°C resulted in a bond strength twice as high than if no heating was used [52].

The bond strength of resin composite to a pre-treated ceramic restoration has been described to be negatively influenced by external factors like water sorption [52], thermocycling [22,59], and fatigue [60]. Contamination of the pre-treated surface with die stone [61], latex gloves [62], saliva [46,59], silicone-based fit-checker paste [63,64], and try-in paste [65] will also lower the bond strength. Several cleaning methods were proposed to restore the original bond strength. In case of contamination with saliva, re-etching the inner side of the porcelain with 37% phosphoric acid restored the bond strength [46,66]. Acetone cleaning, after removal of the try-in paste, produced a marked reduction in bond strength [61,65]. This cleaned surface had to be silanated again to restore the original bond strength [65]. A decreased bond strength due to contamination with fit-checker paste was restored by re-etching and silanizing the porcelain surface [64], whereas Sheth et al. [63] reported that the original bond strength could not be restored due to chemical contamination of the porcelain surface.

1.1.3. Luting composite

For cementation of porcelain veneers a light-curing luting composite is preferred [55]. A major advantage of light-curing is that it allows for a longer working time compared with dual cure or chemically curing materials. This makes it easier for the dentist to remove excess composite prior to curing, and greatly shorten the finishing time required for these restorations. In addition, their colour stability is superior compared with the dual-cured or chemical-cured systems. Nevertheless, it is important that there is enough light transmittance throughout the porcelain veneer to polymerise the light-curing luting composite. The porcelain veneer absorbs between 40–50% of the emitted light. The thickness of the porcelain veneer is the primary factor...
Table 1
Descriptive statistics of clinical trials involving porcelain veneers (evaluation criteria*: color (1), surface texture (2), wear (3), marginal adaptation (4), marginal discoloration (5), caries (6), fracture (7), retention (8), post-operative sensitivity (9), gingiva response (10), patient satisfaction (11))

<table>
<thead>
<tr>
<th>Author</th>
<th>Number of veneers</th>
<th>Number of patients</th>
<th>Porcelain/adhesive-system</th>
<th>Type of preparation</th>
<th>Observation-period</th>
<th>Evaluation criteria*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clyde and Gilmoure [42]</td>
<td>200</td>
<td>Not specified</td>
<td>Chameleon/Terec)/Duo-cure (Terec)</td>
<td>Feathered incisal edge Incisal bevel Palatal overlap</td>
<td>1–30 months</td>
<td>1,7,8,9,10</td>
</tr>
<tr>
<td>Calamia [89]</td>
<td>115</td>
<td>17</td>
<td>Chameleon (Terec)/Comspan + Ultrabond (Den-Mat)</td>
<td>No preparation Slight incisal overlap</td>
<td>2–3 y</td>
<td>4,5,6,7,8,10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(USPHS criteria)</td>
</tr>
<tr>
<td>Jordan et al. [90]</td>
<td>80</td>
<td>12</td>
<td>Not specified/dual cure (not specified)</td>
<td>Conventional (no incisal overlap)</td>
<td>4 y</td>
<td>1,2,3,4,6,8,9,10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(modified Ryge criteria)</td>
</tr>
<tr>
<td>Rucker et al. [84]</td>
<td>44</td>
<td>16</td>
<td>Vitadur-N/Vita/ Heliolink + Dual cement (Vivadent)</td>
<td>Incisal bevel</td>
<td>2 y</td>
<td>1,4,7,8,10,11</td>
</tr>
<tr>
<td>Christensen and Christensen [91]</td>
<td>163</td>
<td>45</td>
<td>Cerinate (Den-Mat)/Ultrabond (Den-Mat)</td>
<td>Feathered incisal edge Feathered incisal edge</td>
<td>3 y</td>
<td>1,4,5,6,7,10,11</td>
</tr>
<tr>
<td>Nordbq et al. [85]</td>
<td>135</td>
<td>41</td>
<td>Ceramco (Ceramco Inc.)/Porcelite LC (Kerr)</td>
<td>Conventional (no incisal overlap)</td>
<td>3 y</td>
<td>3,4,5,7,8</td>
</tr>
<tr>
<td>Jäger et al. [86]</td>
<td>80</td>
<td>25</td>
<td>Mirage/Mirage FLC + Mirage Bond (FA Mirage)</td>
<td>Palatal overlap</td>
<td>1–7 y</td>
<td>4(SEM),5,6,7,10,11</td>
</tr>
<tr>
<td>Strassler and Nathanson [83]</td>
<td>291</td>
<td>60</td>
<td>Cerinate (Den-Mat)/Ultrabond (Den-Mat)</td>
<td>No preparation Conventional (no incisal overlap)</td>
<td>18–42 months</td>
<td>1,4,5,7,8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(modified USPHS criteria)</td>
</tr>
<tr>
<td>Strassler and Weiner [92]</td>
<td>115</td>
<td>21</td>
<td>Cerinate (Den-Mat)/Ultrabond (Den-Mat)</td>
<td>No preparation Conventional (no incisal overlap)</td>
<td>7–10 y</td>
<td>1,4,5,6,7,8</td>
</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(modified USPHS criteria)</td>
</tr>
<tr>
<td>Walls [93]</td>
<td>54</td>
<td>12</td>
<td>Fiber reinforced porcelain (not specified)/Heliolink (Vivadent) + Gluma (Bayer)</td>
<td>Special preparation for worn teeth</td>
<td>5 y</td>
<td>5,7,8,10</td>
</tr>
<tr>
<td>Meijering [41]</td>
<td>56</td>
<td>Not specified</td>
<td>Flexo-ceram (Elephant Ceramics)/not specified</td>
<td>Conventional (no incisal overlap)</td>
<td>2.5 y</td>
<td>1,4,5,6,7,8,9,10,11</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(modified USPHS criteria)</td>
</tr>
<tr>
<td>Peumans et al. [87]</td>
<td>87</td>
<td>25</td>
<td>GC Cosmotech Porcelain/GC Cosmotech Bonding Set (GC) + Scotchbond 2 (3M)</td>
<td>Palatal overlap Palatal overlap</td>
<td>5–6 y</td>
<td>1,2,4,5,6,7,8,10,11</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kihn et al. [88]</td>
<td>59</td>
<td>12</td>
<td>Ceramic Colorlogic/Ceramco Colorlogic Bonding System</td>
<td>Conventional (no incisal overlap) Palatal overlap</td>
<td>48 months</td>
<td>1,4,5,6,9,10</td>
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Table 2
Results of clinical trials involving porcelain veneers

<table>
<thead>
<tr>
<th>Author</th>
<th>Retention + Fracture rate (%)</th>
<th>Excellent margins (%)</th>
<th>Microleakage (%)</th>
<th>Caries (%)</th>
<th>Periodontal health</th>
<th>Maintenance of aesthetics (%)</th>
<th>Patient satisfaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clyde and Gilmoure [42]</td>
<td>1</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>Excellent (not specified)</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Calamia [89]</td>
<td>3</td>
<td>93</td>
<td>17</td>
<td>1</td>
<td>Acceptable</td>
<td>100</td>
<td>–</td>
</tr>
<tr>
<td>Jordan et al. [90]</td>
<td>3</td>
<td>83</td>
<td>–</td>
<td>0</td>
<td>Excellent</td>
<td>100</td>
<td>–</td>
</tr>
<tr>
<td>Rucker et al. [84]</td>
<td>0</td>
<td>100</td>
<td>–</td>
<td>–</td>
<td>Excellent (not specified)</td>
<td>100</td>
<td>100% excellent</td>
</tr>
<tr>
<td>Christensen and Christensen</td>
<td>13</td>
<td>65</td>
<td>8</td>
<td>1</td>
<td>Slight gingival irritation</td>
<td>100</td>
<td>87% excellent</td>
</tr>
<tr>
<td>Nordbq et al. [85]</td>
<td>5</td>
<td>Not specified</td>
<td>Negligible</td>
<td>–</td>
<td>–</td>
<td>100</td>
<td>–</td>
</tr>
<tr>
<td>Jüger et al. [86]</td>
<td>1</td>
<td>55</td>
<td>1</td>
<td>1</td>
<td>Excellent</td>
<td>–</td>
<td>84% excellent</td>
</tr>
<tr>
<td>Strassler and Nathanson [83]</td>
<td>1.7</td>
<td>96</td>
<td>0</td>
<td>0</td>
<td>–</td>
<td>100</td>
<td>–</td>
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<td>Strassler and Weiner [92]</td>
<td>7</td>
<td>88</td>
<td>14</td>
<td>1</td>
<td>–</td>
<td>100</td>
<td>–</td>
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<tr>
<td>Walls [93]</td>
<td>14</td>
<td>Not specified</td>
<td>28</td>
<td>–</td>
<td>Excellent</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Meijering et al. [41]</td>
<td>Not specified</td>
<td>98</td>
<td>22</td>
<td>0</td>
<td>Excellent</td>
<td>100</td>
<td>93% excellent</td>
</tr>
<tr>
<td>Peumans et al. [87]</td>
<td>1</td>
<td>14</td>
<td>25</td>
<td>2</td>
<td>Slight gingival irritation</td>
<td>100</td>
<td>80% excellent</td>
</tr>
<tr>
<td>Kihn et al. [88]</td>
<td>0</td>
<td>85</td>
<td>2</td>
<td>0–1</td>
<td>No gingival response</td>
<td>100</td>
<td>/</td>
</tr>
</tbody>
</table>
determining the light transmittance available for polymerisation [67–73]. The colour and the opacity of the porcelain would have less influence on the amount of absorbed light [69,72,73]. Linden et al. [72] reported that the opacity of porcelain became more important for facings with a thickness of 0.7 mm or more. Consequently, the presence of a porcelain veneer increases the setting time of the resin composite used beneath the veneer [69–72]. O’Keefe et al. [73] argued that it was necessary to double the recommended exposure time.

In case of porcelain with a thickness of more than 0.7 mm [72], light-cured resin composites do not reach their maximum hardness. A dual-cured luting composite, which contains the initiation systems for both chemically and light-cured composites, is advisable in these situations. With these latter luting agents a stronger bond can be obtained with the porcelain [68]. Also higher values of hardness were reported for the dual-cure resin cements than for the luting composite because of their higher degree of polymerisation [72,74].

Regarding the classification of luting composites, Albers [55] ranked these luting composites following the classification of resin composites for restorative purposes proposed by Lutz and Phillips [75]. According to Inokoshi et al. [76], it is difficult to classify the luting composites following these criteria because their high content of small particles requires that many of them would be classified as hybrid resins or heavily filled resins. A classification of 14 dual-cure luting composites was made according to their maximum filler size. This maximum filler size varied extremely from less than 1 to 250 µm. The predominant filler size for all products was much smaller than the maximum filler size. The filler weight varied from 36 to 77%. No correlation was observed between filler loading, maximum filler size and consistency of these dual-cured luting composites, whereas a strong correlation was found between the consistency and the film thickness of the luting agents. This relation was supported by the temperature dependence of the film thickness reported for these dual-cure luting composites [77]. The great diversity in the currently available products makes clear specification for luting composites urgently needed.

1.1.4. The adhesion complex: tooth/luting composite/porcelain

The adhesion complex porcelain/luting composite/tooth was studied by Stacey [22]. He reported that a very strong complex was obtained in vitro by luting the porcelain veneer. The strength of the combined porcelain/luting composite/enamel bond (63 MPa) was significantly higher than the separate composite/etched enamel (31 MPa) and luting composite/etched-and-silanized porcelain (33 MPa) bond strengths. This assumes that a close apposition of the enamel and the porcelain surface synergistically influences the bond strength of the luting composite/enamel and luting composite/porcelain bonds. In addition, Andreasen et al. [78] and Stokes and Hood [79] noted that extracted incisors restored with porcelain veneers were recovered to their original strength. A laboratory investigation analysing ultra-morphologically the adhesive interface of porcelain veneers bonded to tooth structure confirmed the high retention of bonded porcelain veneers [50]: FE-SEM photographs showed a strong micro-mechanical interlocking of the luting composite in the micro-retentive pits of the acid-etched tooth surface at one side and in the etch pits of the acid-etched porcelain surface at the other side (Fig. 2).

Magne and Douglas [80] also demonstrated that porcelain veneers restore the mechanical behaviour and microstructure of the intact tooth in vitro even when they are bonded to an extensive dentin surface using an optimised application mode of dentine adhesives. Nevertheless, significant cyclic temperature changes can induce the development of flaws in porcelain veneers. A sufficient and even thickness of ceramic combined with a minimal thickness of luting composite will provide the restoration with a favourable configuration with regard to crack propensity, namely, a ceramic and luting composite thickness ratio above 3 [81]. This ratio also appears to have a relevant influence on the stress distribution in porcelain laminates. Restorations that are too thin, combined with poor internal fit, resulted in higher stresses at both the surface and interface of the restoration [82].

Ultimately, the clinical relevance of these in vitro results must be determined in vivo. A review of clinical trials involving porcelain veneers, that were conducted during the last 10 years, is summarised in Table 1 with their respective descriptive statistics (Table 1) and results (Table 2). These in vivo results confirmed the strong bond between a porcelain veneer and the underlying tooth tissue as most short and medium-term clinical studies reported a very low failure rate (0–5%) due to loss of bonding and fracture [42,83–88]. Somewhat higher failure rates were noted by Christensen and Christensen [91], 13% after three years and by Strassler and Weiner [92], 7% after 7–10 years. Walls [93] also observed a high number of fractures and/or loss of porcelain veneers (14%) after five years of clinical functioning. Unfavourable occlusion and articulation seemed to have been a determining factor for the high failure rate of porcelain veneers as the latter restorations were placed for aesthetic and functional reconstruction of fractured and worn anterior teeth in patients with a history of bruxism. The large exposed dentine surfaces to be bonded in these fractured and worn teeth (using a third generation dentin adhesive) may also have contributed to the high failure rate.

Some authors [94,95] reported higher failure rates in vivo when porcelain veneers were partially bonded to underlying composite restorations. This bonding is based on delayed resin-to-resin bonding, which may decrease the bond strength of the porcelain veneer–tooth complex.

As a conclusion, in vitro and in vivo studies indicated that porcelain veneers are strong and durable restorations in the medium to long term when enough intact tooth tissue is left
to bond the porcelain veneer and when occlusion and articulation are not pathological.

1.2. Marginal adaptation of the porcelain veneer

For any cemented restoration the weak link is at the restoration-cement–tooth interface. In porcelain veneers the composite luting agent is the weak link in the system. When used as a luting agent, the bulk of composite resin is greatly reduced. However, there is still polymerisation volumetric shrinkage in the amount of 2.6–5.7% [96], which may create a marginal opening or loss of the marginal seal. The thermal expansion coefficient (TEC) is also different from the tooth tissues and the porcelain. Finally, composite resins may wear and the wear will be greater in case of larger gap widths compared to smaller ones [97]. In addition, in vitro studies have demonstrated a dissolution of the resin matrix of composite resin in oral fluids [98–100]. Therefore it is desirable to minimise the composite component and maximise the porcelain component by having as close an adaptation of the porcelain veneer as possible.

Sorensen et al. [101] compared in vitro the marginal fit of porcelain veneers fabricated by the two procedures described above: the platinum foil technique and the refractory die technique. They reported that the mean vertical marginal discrepancy (for all positions combined) for platinum foil veneers (187 µm) was significantly less than that for veneers made with the refractory die technique (242 µm). The same observation was done by Sim and Ibbetson [102] (60 versus 290 µm) and Wall et al. [103] (74 versus 132 µm), although they reported smaller marginal gap widths. This finding seems however incongruous, considering that the platinum foil occupies 25 µm. Lim and Ironside [104] reported that divesting with aluminium oxide abrasive may account for inadvertent abrasion of the delicate inner porcelain surface and causes larger marginal discrepancies (114 µm with sandblasting versus 97 µm without sandblasting).

With the refractory die technique, the importance of matching the thermal expansion coefficient between the refractory die and the ceramic must be emphasised in order to fabricate restorations with a significantly improved marginal accuracy [105]. Intermixing of individual ceramic and refractory products seems to be commonplace in many laboratories with some combinations having different thermal expansion coefficients [43].

For both fabrication techniques, the marginal openings at the gingivo-proximal corners were two to four times larger than at the mid-labial position [101,102,106]. This is probably the result of the shrinkage of porcelain towards the region of greatest bulk (the centre) and the geometry of the margins. Clinically this poorer fit at the gingivo-proximal corners of the veneers would be further compounded by the difficulty in access for finishing of the luted veneers in these regions.

When luting porcelain veneers it is important that the marginal discrepancies are completely filled with the luting composite, in order to polish the cement layer to a smooth margin. Harasani et al. [106] observed after finishing of the veneers still a considerable amount of excess luting agent at the veneer margins. Also Coyne and Wilson [107] reported that only a small proportion of the margins of each porcelain veneer was found to have an ideal marginal adaptation microscopically. Hannig et al. [108] noted that especially the cervical region seems to be a problematic area to achieve perfect marginal adaptation.

Tay et al. [109] advised to remove the excess of non-polymerised composite cement with a brush moistened with bonding resin. This will reduce the dragging out tendency of the resin out of the marginal gap and ensure a smoother margin that is polishable.
Finishing of the veneer margins corrects the inherent marginal defects but results in removal of the glaze from the porcelain [87] (Fig. 3). This will cause increased plaque retention and gingival reaction on the one hand and wear of the antagonistic elements on the other hand, unless the porcelain can be polished to a smooth surface.

Some authors showed that polishing procedures can produce a polished surface, which is equal to a glazed porcelain surface [110–112]. While these polishing instruments perform satisfactorily on flat accessible surfaces at high speeds, none of them are well suited for finishing crucial gingival or interproximal regions of a bonded veneer. Haywood et al. [113] evaluated finishing and polishing in these crucial areas in vitro. According to these authors, a finish equal or superior in smoothness to glazed porcelain was achieved through the use of a series of finishing grit diamonds (Micron Finishing System) followed by a 30-fluted carbide bur and diamond polishing paste. Other finishing combinations produced surface textures, which were not as smooth as glazed porcelain. Polishing under waterspray produced also a smoother surface for a given diamond sequence than did dry polishing [114]. However, the effect of all these finishing procedures at the cervical margins of the veneer with their difficult accessibility for polishing instruments, must be evaluated in vivo.

Regarding the marginal adaptation of porcelain veneers after several years of clinical functioning, most in vivo
studies reported a relatively high number of restorations with an excellent marginal adaptation (65–98%) [41, 83, 84, 88–92], while only few clinical studies reported that small marginal defects were frequently observed along the entire outline of the porcelain veneer after five years of functioning [86, 87] (Table 2). SEM examination showed that these small marginal defects were due to the wearing out of the composite luting agent and loss of bonding [86, 87]. A similar phenomenon was reported as submargination in several in vivo studies of porcelain inlays [115–117].

Further research should be directed towards improvement of marginal adaptation of the porcelain veneers. Attention must be given to the laboratory procedure to reduce the marginal gap width and to the finishing procedure to diminish the excess of resin composite at the margins. Finally more wear-resistant luting composites should be developed.

1.3. Microleakage at the tooth/luting composite/porcelain interface

The polymerisation shrinkage of the luting composite and the difference in thermal expansion coefficient between the luting composite and both the tooth and the porcelain veneer causes stress at the tooth/luting composite/porcelain interface. According to the theories by Feilzer et al. [118], there is only a limited potential for relaxation of polymerisation stress due to flow because the luting composite is bonded at all sides in a narrow “gap” with only a limited area of unbonded surface. Consequently, Feilzer et al. [119] found that when the thickness of the resin composite is thinned down, as in the case of a luting agent, the wall-to-wall polymerisation shrinkage might be three times the normal linear contraction of bulk resin composite. Residual polymerisation stress could then be expected to be even greater
than that reported for resin composite restorations. Due to this contraction stress there exists a competition between the adhesive forces of the two bonded interfaces: the porcelain/luting composite interface and the luting composite/tooth interface. The interface with the lowest adhesive forces will fail namely the luting composite/tooth interface. Microleakage will occur at this interface and may then lead to staining, post-operative sensitivity and recurrent caries.

Microleakage at the luting composite/porcelain interface was negligible [101,120,121]. At the interface luting composite/tooth the microleakage was minimal when the preparation margins were located completely in enamel [101,120–123]. Only at the cervical margin, microleakage was more pronounced. This would be due to the presence of aprismatic enamel in the cervical region [50,124] (Figs. 4 and 5). Porcelain veneer preparations generally end in this region of aprismatic enamel, which therefore may be largely responsible for the poor marginal sealing reported at the cervical margins of porcelain veneers in vitro [101,120–123]. When the cervical preparation margin was located in dentine, significantly greater microleakage was recorded at the luting composite/tooth interface [125]. The use of a third generation dentine bonding agent can reduce the occurrence of microleakage according to several authors [120,125] in contrast with the results obtained by Sim et al. [123], who reported that none of the tested (third generation) dentine bonding agents significantly reduced microleakage at the dentine margins. Dietschi et al. [126] reported an obvious reduction in marginal leakage of ceramic inlays when bonded to dentin using two modern dentine adhesives, although the integrity of the adhesive interface did not yet appear optimal in dentine bonded ceramic restorations because bonding failures occurred mainly between the hybrid layer and the overlaying resin. In another in vitro study debonding was never noticed along the luting composite/dentine interface when a modern multi-step total-etch dentin adhesive system was used [50] (Figs. 6 and 7). Magne and Douglas [80] noticed in vitro that the method of dentin adhesive application during placement of the porcelain veneer had an influence on the quality of the luting composite dentin/interface. Their scanning electron microscope observations demonstrated that the traditional application of a multi-step total etch dentin adhesive (dentin adhesive applied when proceeding to luting the veneer) was associated with bonding failures between the hybrid layer and the overlaying resin, whereas unbroken and continuous interfaces were obtained with a new method using the same dentin adhesive (dentin adhesive applied to dentin and cured before taking the impression of the veneer). However, none of the modern adhesive systems appears yet to be able to guarantee hermetically sealed restorations with margins free of discoloration for a long time [25].

Another effective method to reduce microleakage is by post-finishing sealing the margins of the veneer with a bonding resin [125]. Further research is necessary to evaluate the retention of the sealer.

In addition to the location of the preparation margins, the type of luting composite determines the occurrence of microleakage as the thermal expansion coefficient and the amount of polymerisation shrinkage vary among the type of resin composite. A high filler loading reduces the thermal expansion coefficient and polymerisation shrinkage. Because of these reasons, a luting composite with an optimal filler loading is preferred to lute the porcelain veneers [101,121,122,123]. However, the viscosity of such cements is high and hence the positioning of the veneer during the luting procedure may be delicate. The luting procedure with these highly filled luting composites can be simplified by using an ultrasonic insertion technique [127]. Clinical confirmation of this method is however required.

Light-cured and dual-cured luting composites show a similar leakage pattern at the luting composite/tooth interface according to Zaimoglu et al. [122], whereas Jankowski et al. [128] observed less microleakage when using dual-cured luting composites.

In clinical studies, microleakage was more frequently observed when dentine was exposed during preparation for porcelain veneers [89], even when a third generation dentine adhesive system was used [87,93]. In other clinical studies of porcelain veneers with complete intra-enamel preparations, microleakage was reported less frequently [83,85,88,91,92]. Finally, microleakage was rarely associated with the presence of caries in vivo [41,83,86–92].

As a conclusion, microleakage can be minimised by locating the preparation margins of the veneer in enamel and by selecting a highly filled luting composite.

1.4. Periodontal response

Porcelain is considered as the most aesthetic and biocompatible material in dentistry with the ability to imitate sound enamel. Several studies showed that porcelain retains plaque less than other restorative materials or enamel [129–132], that the plaque is removed more rapidly from porcelain surfaces and/or that the bacterial plaque vitality on these surfaces was smaller [133]. The low surface roughness of the glazed porcelain may to a large part be responsible for this phenomenon [134]. Based on these observations one would expect no or even a positive reaction of the marginal gingival tissues towards porcelain veneers.

Several short-term [89,135] and medium-term [88,93,136] clinical studies of porcelain veneers confirmed this expectation. They reported no increase of even a decrease in plaque accumulation on these restorations. Kourkata et al. [135] even described a significant lower bacterial plaque vitality immediately after placement of the porcelain veneers. Peumans, however, observed a slight increase in plaque retention at the cervical margins of 5-year old porcelain veneers [137]. This slight increase was explained by the increased surface roughness at the cervical
border of the restoration caused by removal of the glaze of the porcelain during finishing with microfine finishing diamonds (Fig. 3). In addition to this roughened cervical border, the presence of small cervical marginal defects can lead to an increased plaque retention [87].

Concerning the gingival response, most clinical studies observed no change in gingival health at the restored teeth [41,42,84,86,88–90,93,136] (Table 2). Only a few clinical studies reported a slight gingival inflammation at the restored teeth [91], especially in patients with a moderate or bad oral hygiene [137].

According to Pippin et al. [136], the location of the cervical extension of the restoration in location to the gingival margin also plays an important role in the reaction of the gingival tissues. They reported that the gingival reaction increased as the extension was located closer to or below the gingival margin, however, the gingival reaction for porcelain veneers was at the same location lower than for the metal ceramic restorations.

In conclusion, no or a minimal periodontal response can be expected at teeth restored with porcelain veneers. An optimal oral hygiene of the patient and smoothly finished margins are important factors to maintain an optimal periodontal health around the restored teeth.

1.5. Aesthetic characteristics of porcelain veneers

There is a general agreement among the practitioners that porcelain veneers will continue to play a vital role in elective dental aesthetics. This places high demands on predictability, especially with colour matching and masking methods. The final shade of the veneers depends not only on the colour, opacity and thickness of the porcelain but also on the colour of the underlying tooth and the colour and thickness of the luting composite [138–143].

Colour matching of one discoloured tooth with a porcelain veneer to the surrounding natural teeth must be considered as most difficult. It is impossible to mask a strong discolouration by a thin layer of porcelain (0.3–0.7 mm) without making the restoration opaque and lifeless. Consequently, the restored tooth will never have the same translucency as the surrounding natural teeth. [14,15,42,55,87].

Regarding the aesthetics (colour stability and surface smoothness) of porcelain veneers after several years of clinical functioning, all clinical studies confirmed the maintenance of aesthetics of porcelain veneers in the short term and in the medium to long term (Table 2). In addition, patient acceptance of porcelain veneers in these clinical studies was high. The percentage of patients that were completely satisfied with the porcelain veneers varied from 80 to 100% (Table 2). Some studies even reported an increase in patient satisfaction after several years [91,144]. This increase was explained by the habituation of the patients to the aesthetic improvement of their dentition with porcelain veneers.

2. Conclusion

The adhesive porcelain veneer complex appeared to be a very strong complex in vitro and in vivo. An optimal bond was obtained if the preparation was located completely in enamel, if correct surface treatment procedures were carried out and if a suitable composite luting agent was selected. However, from an aesthetic and periodontal point of view a complete intra-enamel preparation cannot always be realised. The quality of the restoration was inferior if dentine was exposed to a large extent, as the current dentin bonding agents are not yet able to prevent microleakage at the dentin margins in the long term.

The periodontal response to porcelain veneers varied from clinically acceptable to excellent. Regarding the aesthetic properties of the porcelain veneers, these restorations maintained their aesthetic characteristics in the medium to long term and patient satisfaction was high. The major shortcoming of porcelain veneers was the relatively wide marginal discrepancy. At these marginal openings the luting composite was exposed to the oral environment and the wear resistance of the composite luting agents was not yet optimal.

Nevertheless, these shortcomings had no direct impact on the success of porcelain veneers in the medium term, however, their influence on the overall clinical performance in the long term is still unknown.

References


