To what extent does the longevity of fixed dental prostheses depend on the function of the cement?
Working Group 4 materials: cementation

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Abstract
Aims/Background: The objective of this review was to define the impact of cementation mode on the longevity of different types of single tooth restorations and fixed dental prostheses (FDP).

Methods: Literature search by PubMed as the major database was used utilizing the terms namely, adhesive techniques, all-ceramic crowns, cast-metal, cement, cementation, ceramic inlays, gold inlays, metal-ceramic, non-bonded fixed-partial-dentures, porcelain veneers, resin-bonded fixed-partial-dentures, porcelain-fused-to-metal, and implant-supported - restorations together with manual search of non-indexed literature. Cementation of root canal posts and cores were excluded. Due to lack of randomized prospective clinical studies in some fields of cementation, recommendations had to be based on lower evidence level (Centre of Evidence Based Medicine, Oxford) for special applications of current cements.

Results: One-hundred-and-twenty-five articles were selected for the review. The primary function of the cementation is to establish reliable retention, a durable seal of the space between the tooth and the restoration, and to provide adequate optical properties. The various types of cements used in dentistry could be mainly divided into two groups: Water-based cements and polymerizing cements. Water-based cements exhibited satisfying long-term clinical performance associated with cast metal (inlays, onlays, partial crowns) as well as single unit metal-ceramic FDPs and multiple unit FDPs with macroretentive preparation designs and adequate marginal fit. Early short-term clinical results with high-strength all-ceramic restorations luted with water-based cements are also promising. Current polymerizing cements cover almost all fields of water-based cements and in addition to that they are mainly indicated for non-retentive restorations. They are able to seal the tooth completely creating hybrid layer formation. Furthermore, adhesive capabilities of polymerizing cements allowed for bonded restorations, promoting at the same time the preservation of dental tissues.

The longevity of indirect fixed dental prostheses (FDPs) could be affected by multiple factors including the cementation mode. The primary function of the cementation is to establish reliable retention, a durable seal of the space between the tooth and the restoration, and to provide adequate optical properties especially for tooth-colored ceramic or polymeric FDPs. Various types of cements with different properties are available in dentistry that can primarily be divided into two groups (Table 1): water-

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Based cements and polymerizing cements. As the use of water-based cements is strongly dependent on the macrotetensive tooth preparation and excellent marginal fit of the restoration, polymerizing cements can confer adhesive properties to both the tooth tissues and the restorative material. They also present negligible solubility and significantly improved optical properties. The use of polymerizing adhesive cements for translucent restorative materials such as glass-ceramics or reinforced polymeric restorations enables an outstanding esthetic outcome and simultaneously reduces the need for macrotetention. This could be considered as a high impact on the preservation of sound tooth tissues [Edelhoff & Sorensen 2002a, 2002b]. Not only for the bonded indirect FDPs but also for all types of restorations, polymerizing cements are considered in general as better alternatives as improved retention as well as a better seal of the margins can be established.

Selection of appropriate cementation mode is frequently affected by the restorative material properties, marginal fit, type of restoration, and the surface-conditioning method [Özcan et al. 1998]. Furthermore, the properties of the cement (i.e., viscosity, biocompatibility, adhesive potential, solubility, water uptake, color stability, wear resistance, working and setting characteristics, sealing ability, radio-opacity) as well as various clinical confounding factors (i.e., occlusion, preparation design, moisture control, type of build-up material, type of supporting tooth structure, surface roughness, margin location, tooth location, amount of tooth destruction, and abutment mobility) determine the selection of the cement.

A high variety of cements is available today in dentistry with a continuously expanding range of new products and applications [Rosenstiel et al. 1998; Diaz-Arnold et al. 1999; Powers & Sakaguchi 2006]. The purpose of this review therefore was to define the impact of cement type and cementation mode on the longevity of different types of single- and multiple-unit FDPs. Owing to lack of randomized prospective clinical studies in some application fields, recommendations must be based on lower evidence level [Centre of Evidence Based Medicine, Oxford] for applications of current cements.

Water-based cements

The most commonly used water-based permanent luting agents are zinc phosphate and glass-ionomer cements. Zinc phosphate cement has served for decades as the universal cement for different applications in restorative dentistry relying on the retention and resistance form of the tooth preparation and an adequate marginal fit. Because of its long history of successful clinical use, associated with cast and metal-ceramic restorations, zinc phosphate cement is considered as the ‘reference’ or ‘gold standard’ [Kerschbaum et al. 1991, 1997; Creugers et al. 1994]. In an in vitro study, Utz et al. [1989] categorized the sealing capacity of zinc phosphate cement as the most favorable when compared with glass-ionomer cement. These findings are in compliance with the results of an in vivo study where a higher solubility of glass-
ionomer cement was detected compared with zinc phosphate cement (Phillips et al. 1987). In contrast, in an in vivo evaluation of marginal fit of restorations before and after cementation, Kern et al. (1993) could show that cast copings luted with glass-ionomer cement exhibited a better fit than those luted with zinc phosphate cement. In an in vitro study, glass-ionomer cement used for crown cementation was more resistant to dynamic load than zinc phosphate cement (Wiskott et al. 1997). Clinical data on the longevity of ceramic inlays placed with water-based cements are limited in the literature. Long-term data are almost only available on cast-gold inlays luted with zinc phosphate cement. In a retrospective clinical study, 2717 gold restorations were observed and after 10 years, 231 (81.9%) had to be removed (Fritz et al. 1992). For one-surface inlays, a success rate of 65%, for two-surface inlays 60%, and for three-surface inlays 68% was calculated. The success rate for cast-gold onlays and partial crowns was 70%. The reasons for failures were recurrent caries (29.2%), endodontical complications (17.8%), insufficient fit (13.5%), lack of retention (13.1%), and caries in untreated areas (12.7%). Erpenstein et al. (2001) subsequently, in a retrospective clinical study, investigated 2071 cast-gold inlays cements with zinc phosphate cement. The 20-year Kaplan–Meier survival rate for restoration-bearing teeth was 98.9%. This result, however, decreased to 73.4% at the 25-year follow-up. Gold inlays inserted into maxillary teeth had significantly better survival probabilities after this period than those inserted into the mandible. Based on the number of surfaces involved, 52% of one-surface inlays, 64.3% of two-surface inlays, 75.8% of three-surface inlays, and 84.8% of inlays with more than three surfaces were still in situ after 25 years. In a further retrospective clinical evaluation of 1314 cast-gold restorations conducted by Donovan et al. (2004), almost 90% of the restorations had been in service for over 9 years, 72% for over 20 years, and 45% from 25 to 52 years. Restorations were evaluated in terms of marginal integrity, anatomic form, and surface texture. Ninety-six percent of the evaluated restorations were rated excellent. Sixty restorations required removal and replacement, yielding an overall survival rate of 95.4%. The survival rates at various time periods were 97% at 9 years, 90.3% at 20 years, 94.9% at 25 years, 98% at 29 years, 96.9% at 39 years, and 94.1% of the restorations were in place after more than 40 years. According to the cited clinical studies, accurately fabricated cast-gold inlays, onlays, and partial crowns cements with zinc phosphate cement can provide very predictable, long-term clinical service.

The influence of cementation mode on the clinical performance of 115 fired ceramic inlays in a 6-year clinical follow-up was investigated by Van Dijken et al. (1998). The inlays were either placed adhesively \( (n=58) \) or conventionally with glass-ionomer cement \( (n=57) \) in a split-mouth design. After 6 years of clinical service, a 12% failure rate with adhesively placed inlays and 26% with glass-ionomer cement were detected. Based on these results, it was concluded that the longevity of ceramic inlays is largely related to adhesive cementation.

In a further study by Gemalmaz et al. (2001), 45 fired ceramic inlays were bonded with three different luting agents. Fifteen of the inlays were inserted with one of the three different luting agents, namely two resin-based cements and one polyacrylic acid-modified glass-ionomer cement. The restorations were evaluated using modified USPHS criteria for a period between 3 and 46 months, with a mean of 26.3 months after insertion. The Kaplan–Meier statistical analysis was used to calculate the survival rate of the inlays. The fracture rates observed for resin-based cements were 13%, and 33% for polyacrylic acid-modified glass-ionomer cement. It was concluded that the use of a polyacrylic acid-modified glass-ionomer cement resulted in a higher fracture rate and loss of marginal adaptation in fired ceramic inlays. Although the study was not long term, during the observation period the marginal adaptation of the luting agent was more durable at the enamel–cement interface than that at ceramic–cement interface. These clinical findings were confirmed by the results of an in vitro study, in which resin-modified glass-ionomer cement was not recommended as a luting material for feldspathic partial ceramic crowns due to a significantly higher incidence of microleakage (Federlin et al. 2005).

As placement of fired ceramic inlays with water-based cement increased the fracture rate more than twice, this cementation mode cannot be recommended for predictable long-term restorations.

Owing to their reliability and durability, conventionally cemented cast-metal and metal-ceramic restorations with a complete crown preparation design were accepted as the treatment of choice for single- or multiple-unit FDPs for decades (Kerschbaum et al. 1991, 1997; Creugers et al. 1994). When conventional cementation is used, macroretentive preparation is considered to be an important parameter for success (Shillingburgh et al. 1997). In a literature review, Goodacre et al. (2001) suggested the following guidelines for tooth preparation when conventional cementation is to be applied: teeth should be prepared with 10–20° of total occlusal convergence and a minimal occlusocervical height of 4 mm for molars and 3 mm for other teeth. In another in vitro study, 12° of taper was detected as the transition point where the slope of the graph of cycles to dislodgement as a function of taper abruptly changed (Cameron et al. 2006). When the above features are missing, the teeth should be modified with auxiliary resistance features such as axial grooves or boxes, preferably on proximal surfaces (Goodacre et al. 2001). In a 10-year clinical trial conducted by Jokstad & Mjör (1996) on 81 fixed protheses placed on 135 abutment teeth, no differences were found between glass-ionomer and a zinc phosphate luting agent in the prognosis. Non-parametric survival estimates indicated that 80–85% of the abutment teeth remained intact after 5 years and 71–81% after 10 years. The prevailing reason for abutment tooth failure was secondary caries \( (n=21) \) and pulp necrosis \( (n=5) \). Hypersensitivity occurred in five teeth restored with glass-ionomer cement.

Unlike metal-based restorations, all-ceramic restorations should not involve any primary retention, as this would produce crack-inducing tensile stresses from the inner surface of the restoration [Anusavice & Hojjatie 1992]. The overall fit of all-ceramic restorations exhibit inferior adaptation compared with their cast-metal or metal-ceramic counterparts [Molin & Karlsson 1993; Albert & El-Mowafy 2004, Sailer et al. 2006]. The large marginal discrepancy and the lack of primary retention have to be compensated by an appropriate cement selection. Bonding glass-ceramic restorations using a resin composite cement significantly increased
the fracture strength compared with cementation with zinc phosphate cement [Scherrer et al. 1996].

Commonly, the high flexural strength and fracture toughness as well as the better fit of new all-ceramic systems including high-strength core materials allow for the use of water-based cements that are primarily based on macromechanical retention. Naert et al. [2005] reported on the crown adaptation, marginal fit, and clinical behavior of all-ceramic full-coverage alumina FDPs [Procera, Gothenburg, Sweden] luted with glass-ionomer cement in one clinical center and followed up to 5 years. The marginal fit and coping adaptation before and after luting were determined by direct measurement as well as after sectioning in an in vitro study. Three-hundred all-ceramic restorations were cemented in 165 patients between 1994 and 1998. Patients were recalled for the assessment of their restorations using the California Dental Association quality evaluation index, their own appreciation, and the reaction of the periodontal tissues. The in vitro data revealed a mean marginal gap of 30 \( \mu \)m, before and after luting of the alumina coping onto the tooth. However, at the deepest part of the chamfer, the gap increased to 135 \( \mu \)m. In the clinical part of the study, only one restoration fractured, while in 6% of the restorations, small chippings of the veneering ceramic were observed. After polishing the chipped areas, no persistent patient complaints remained. At the last recall, 1.8% of the evaluated margins were rated as unacceptable. Dentists rated 72% and 78% of the restorations as excellent for surface, color, and anatomic form, respectively. Eighty-seven percent of the patients rated their restorations more than seven on an ordered analog scale, with a maximum of 10 for esthetics and for function. In another clinical follow-up, 107 anterior and posterior all-ceramic alumina crowns [Procera Alumina AllCeram] placed with glass-ionomer cement were evaluated for 6 years. Six crowns had to be removed because of non-repairable fracture. At 6 years, the cumulative survival rate was 94.3% for all crowns, 96.7% for anterior crowns, and 91.3% for posterior crowns [Walter et al. 2006].

According to the results of the cited studies, the use of water-based cements can be recommended for cast metal [inlays, onlays, partial crowns] as well as metal-ceramic and high-strength all-ceramic full-coverage single- or multiple-unit FDPs with a macroretentive preparation design and adequate marginal fit. However, as the ceramic inlay failure rate was twice as high with water-based or polyacrylic acid-modified glass-ionomer cements compared with polymerizing cements, adhesive cementation should be compulsory for the cementation of silica-based ceramic inlay restorations [Van Dijken et al. 1998; Gemalmaz et al. 2001].

Polymerizing cements

With advances in the field of polymerizing cements with added advantages of bonding to dental tissues and to indirect restorations, conservative preparation designs could be achieved with reduced need for macroretention. The reliable adhesion to enamel achieved with the adhesive techniques has had a major impact on saving the remaining tooth structure and has led to a crucial change in the existing paradigms in tooth preparation. Even adhesive cementation of gold inlays and onlays would allow for conservative tooth preparation [Ohsawa et al. 2004]. However, clinical data proving the longevity of adhesively bonded gold inlays are limited in the dental literature [Miya 1997; Fabianelli et al. 2005].

The marginal adaptation and microleakage of densely sintered alumina all-ceramic and metal-ceramic FDPs using four different cements were evaluated by Albert & El-Mowafy [2004]. Alumina all-ceramic copings had a significantly larger mean marginal gap (54 \( \mu \)m) compared with metal ceramic (29 \( \mu \)m). Marginal gap extension influenced the degree of microleakage. With both types of crowns, resin cement exhibited the lowest percentage of microleakage, whereas the zinc phosphate cement resulted in the most extensive microleakage. In a split-mouth randomized clinical trial, 39 metal-ceramic, and 39 alumina all-ceramic single-unit FDPs retained with resin-modified glass-ionomer and zinc phosphate luting cements were evaluated [Jokstad 2004]. The results showed that a resin-modified glass-ionomer luting cement performed at least as good as zinc phosphate cement to retain single FDPs over a 12-month observation period.

Osman et al. [2006] compared the film thickness and rheological properties of zinc phosphate cement with different polymerizing cements, including Panavia 21, Superbond, All Bond C&B Cement, and Variolink. An initial film thickness of 25 \( \mu \)m was observed and was not significantly different between the cements.

Veneers

The combination of highly translucent ceramics and polymerizing cements has facilitated the clinical use of the adhesive technique and launched innovative restorative treatment options. The increased preservation of enamel promotes a superior adhesion to dentin, less post-cementation sensitivity, improved support to the ceramic restoration, and reduced endodontic intervention [Marinello & Schärer 1987; Scherrer & De Rijk 1993; Scherrer et al. 1996]. Therefore, the preservation of enamel has become an important pre-requisite for preparation design [Belser et al. 1997; Federlin et al. 2005]. Owing to their excellent clinical performance, outstanding esthetics, and minimal invasiveness, resin-bonded veneers offer reliable treatment options with an escalating range of indications [Nattress et al. 1995; Peumans et al. 1998; Magne & Douglass 1999]. In a 15-year clinical evaluation of adhesively luted ceramic veneers, approximately 3500 restorations were observed and 93% of them were classified as successful [Friedman 1998]. Sixty-seven percent of the 245 failed veneer restorations presented fractures, 22% microleakage, and 11% debonding. Increased microleakage was particularly detected when the veneers were bonded to dentin.

In a prospective 10-year clinical trial of 87 ceramic veneers on maxillary anterior teeth [Peumans et al. 2004], 93% of the restorations could be evaluated. Clinical performance was assessed in terms of esthetics, marginal integrity, retention, clinical microleakage, secondary caries, fracture, vitality, and patient satisfaction. Failures were recorded either as ‘clinically unacceptable but repairable’ or as ‘clinically unacceptable with replacement needed.’ The authors reported that ceramic veneers maintained their esthetic appearance after 10 years of clinical service. Only 4% of the restorations needed to be replaced at the
10-year recall. The percentage of restorations that remained ‘clinically acceptable’ [without need for intervention] significantly decreased from an average of 92% at 5 years to 64% at 10 years. Fractures of ceramic (11%) and large marginal defects (20%) were the main reasons for failure. Marginal defects were especially noted at locations where the veneers ended in existing composite fillings. At such vulnerable locations, severe marginal discoloration (19%) and caries (10%) were frequently observed. Most of the restorations that present one or more ‘clinically unacceptable’ problems (28%) were repairable. The authors concluded that labial ceramic veneers luted adhesively represent a reliable, effective procedure for conservative treatment of esthetic anterior teeth. In a further retrospective clinical study on 328 veneers, prepared with a lingual minichamber, a 10-year Kaplan–Meier survival rate of 97% was found [Laubach 2005]. Murphy et al. [2005] investigated in a retrospective study over a time period of 5 years the performance of 62 ceramic laminate veneers delivered by undergraduate dental students. On the date of recall, while 89% of veneers were never debonded or fractured, 6% had to be rebonded since the date of insertion and 5% presented fracture. From this study, it appears that ceramic laminate veneers are successful in the treatment of discolored and irregular-configured anterior teeth. It was shown that undergraduate students were also capable of achieving satisfactory veneer restorations. In all these clinical studies, polymerizing cements were employed.

According to the results of numerous clinical trials for silica-based ceramics, polymerizing resin cements should be the material of choice for cementation. Static and dynamic occlusion, preparation design, presence of composite fillings, dentin exposure, and the adhesive used to bond veneers to tooth substrate were reported to be covariables that could contribute to the clinical outcome of these restorations in the long term [Karlsson et al. 1993; Peumans et al. 2004].

**Inlays**

A review of the clinical survival of direct and indirect restorations in posterior permanent dentition evaluated the longevity and annual failure rates of amalgam, direct composite restorations, compomers, glass-ionomers, and derivative products, composite and ceramic inlays, and cast-gold restorations for Class I and II cavities [Manhart et al. 2004]. The mean annual failure rates for indirect restorations in posterior stress-bearing cavities were 2.9% for composite inlays, 1.9% for ceramic restorations, 1.7% for CAD/CAM ceramic restorations, and 1.4% for cast-gold inlays and onlays. Indirect restorations exhibited a significantly lower mean annual failure rate than direct techniques. The principal reasons for failure were secondary caries, fracture, marginal deficiencies, wear and post-operative sensitivity. Unfortunately, this review article did not concentrate on the effect of cement type.

Fuzzi & Rappelli [1999] evaluated 182 ceramic inlays with 2–11.7 years of clinical service. A success rate of 95% could be predicted at 11.5 years. The excellent longevity proved that adhesively luted ceramic inlays represent a valuable tool for the restoration of posterior teeth. These data agree with the clinical performance of 96 bonded leucite-reinforced hot-pressed glass-ceramic inlays and onlays evaluated in a prospective controlled clinical study [Krämer & Frankenberger 2005] after 8 years of clinical service. The restorations were bonded with an enamel/dentin bonding system and four different resin composite systems. The restorations were assessed after placement by two calibrated investigators using modified USPHS scores and criteria. Eight of the 96 restorations investigated had to be replaced, resulting in an 8% failure rate according to Kaplan–Meier analysis. Six inlays suffered from cohesive bulk fractures and two teeth required endodontic treatment. Ninety-eight percent of the surviving restorations exhibited marginal deficiencies, independent of the luting composite. Heat-pressed ceramic inlays and onlays demonstrated to be successful even in large defects.

In a clinical trial conducted in private practice, 1010 ceramic inlays and onlays manufactured by the Cerec CAD/CAM technique were adhesively placed and observed [Reiss & Walther 2000]. According to the Kaplan–Meier analysis, the probability of survival decreased to 90% after 10 years and 84.9% after 11.8 years, with no further loss at the final observation at 12 years. The size and outline form did not affect the success rate. Premolars rated better than molars. Vital teeth provided better results than non-vital teeth. The application of dentin adhesive increased the probability of success. Even when adhesively luted, the most frequent reason for failures was fracture of ceramic and tooth. In a further prospective evaluation of CAD/CAM-manufactured (Cerec) ceramic inlays cemented with a chemically cured or dual-cured resin composite, 61 Class II Cerec inlays were evaluated after 10 years of clinical service using a slight modification of the USPHS criteria (Sjögren et al. 2004). Fifty-four of the re-evaluated 61 inlays still functioned well at the 10-year recall. During the follow-up period, seven [11%] of the inlays required replacement due to four inlay fractures, one cusp fracture, endodontic problems in one case, and postoperative symptoms in another case. The fractured inlays were all in molars. The estimated cumulative survival rate after 10 years was 89% where 77% was for the dual-cured resin composite-luted inlays and 100% for the chemically cured resin composite-luted ones. The difference was statistically significant. The properties of the luting agents seem to affect the longevity of the type of ceramic inlays evaluated.

Posselt & Kischbaum [2001], on the other hand, evaluated 2328 ceramic inlays that were manufactured chair-side using Cerec technology. The inlays were adhesively inserted at the same appointment. Thirty-five Cerec restorations were judged as having failed and the probability of survival was 95.5% after 9 years. The clinical success was not significantly influenced by restoration size, tooth vitality, treatment of caries, type of tooth treated, or whether the restoration was located in the maxilla or mandible. The most common type of failure was the extraction of a tooth. In this clinical follow-up, 44 randomly selected restorations were examined under a light microscope where an average composite joint width of 236.3 μm was found. Forty-five percent of the restorations exhibited perfect margins, and 47.4% of the investigated cement joint sections showed underfilled margins.

According to this part of the literature review, gold inlays and onlays cemented with zinc phosphate exhibited higher clinical success rates than adhesively luted
ceramic inlays of different fabrications [heat pressed, fired on a refractory die or CAD/CAM] (Molin & Karlsson 2000). As the ceramic inlay failure rate was two times higher when luted with conventional glass-ionomer cement, adhesive placement should be considered as the treatment of choice [Van Dijken et al. 1998, Gemalmaz et al. 2001]. The application of dentin adhesive and the use of chemically polymerized resin composite seemed to be advantageous for the longevity of ceramic inlays [Reiss & Walther 2000, Sjögren et al. 2004]. Under certain restrictions, the absence of enamel margins, or cuspal replacement as well as a solely light-polymerized resin composite significantly affected the quality of the restorations [Federlin et al. 2004; Federlin et al. 2005; Krämer & Frankenberger 2005; Schulte et al. 2005].

FDPs

Unlike metal-based restorations, all-ceramic restorations should not involve any primary retention, as this would produce crack-inducing tensile stresses from the inner surface of the restoration. Certain preparation guidelines that differ from recommendations for metal-supported systems have to be taken into consideration for all-ceramic FDPs [Doyle et al. 1990a, 1990b; Friedlander et al. 1990]. These studies were published on cementation and preparation design for all-ceramic full crowns. The details of these studies have been contradictory with regard to cementation mode, preparation geometry of the margin, angle of convergence, and extent of tooth removal [Doyle et al. 1990b; Meier et al. 1995; Edelhoff et al. 2000]. In vitro investigations have shown that substructures with a high elastic modulus increase the strength of all-ceramic crowns, especially of those fully fabricated out of silica-based ceramic; the residual dentin thickness after preparation therefore may influence the life expectancy of the restoration (Scherrer & De Rijk 1993). A preparation design that requires the removal of large amounts of hard tooth tissues must be rejected for a number of reasons: exposure of dentin near the pulp with a high density of dentin tubules, increased secretion of dentinal fluid, adverse influence on the ratio of residual dentin to cavities (pulp cavity, dentin tubules), increased risk of postoperative sensitivity, and contraindication for young patients with large pulps.

All-ceramic restorations exhibit an inferior overall fit compared with cast metal or metal-ceramic restorations [Molin & Karlsson 1993; Albert & El-Mowafy 2004; Sailer et al. 2006]. The high marginal discrepancy and the lack of primary retention have to be compensated by an appropriate cementation technique. Adhesive bonding represents a fundamental stage in the clinical application of all-ceramic restorations, as this approach has extensive advantages in the preparation design, esthetic appearance, and longevity of the restorations. Several in vitro studies provided information proving that adhesive cementation is capable of sealing inner surfaces and thereby reinforcing silica-based ceramic restorations (Anusavice & Hojjatie 1992; Ludwig & Joseph 1994; Pospiech et al. 1996; Mörmann et al. 1998). Polymerizing cements show further negligible solubility, providing excellent properties to compensate for the insufficient marginal fit of the early all-ceramic systems. However, adhesive cementation procedures require meticulous and skilled work and they are relatively more time consuming. In case of full crown preparation, large areas of dentin are exposed, and adhesive bonding may not always provide a reliable and durable bond. Furthermore, absolute isolation with a rubber dam is not possible in most of the cases and subgingival preparation margins are often unavoidably associated with full-crown preparations. This raises the question as to which cementation technique would be appropriate for the insertion of all-ceramic FDPs. Generally, the high flexural strength and the better fit of new all-ceramic systems including high-strength core materials allow for the use of conventional cements, which are primarily based on macromechanical retention. In the literature, only a few clinical studies are available comparing different cementation modes for all-ceramic FDPs.

Glass-ceramic single-unit FDPs

Edelhoff et al. (2000) investigated leucite-reinforced heat-pressed glass-ceramic crowns (Empress 1) luted with adhesive dual polymerizing composite and zinc phosphate cement. No differences in survival rate (98%) were detected between both groups of glass-ceramic crowns after a 4-year period of clinical service. Cremer & Pfeiffer (2000) placed and evaluated 46 glass-ceramic (Empress 1) crowns and 46 infiltrated alumina ceramic crowns (In-Ceram Alumina) in the posterior area, which were placed either with dual-polymerizing composite or zinc phosphate cement. Within the observation period of 26 months, 59 of 88 all-ceramic crowns were rated to be clinically excellent. Zinc phosphate cement was considered in this clinical study as an acceptable alternative to resin composite luting cement. In two long-term clinical trials over 14 years on different types of Dicor restorations (Malament & Socransky 1999a, 1999b), complete-coverage full-crown FDPs survival improved when restorations were acid-etched with hydrofluoric acid before luting. The survival of restorations with either chamfer or shoulder preparations did not differ when the restoration was etched. The thickness of the restoration also did not relate to the survival. Acid-etched Dicor restorations luted to gold core structures exhibited a significantly better survival rate than restorations luted to dentin. A further evaluation of this study after 16 years of clinical service confirmed that acid-etched Dicor restorations survived better than non-acid-etched restorations when luted to dentin preparatons and that the glass-ionomer exhibited a lower relative risk for failures than zinc phosphate cement (Malament & Socransky 2001). Kinnen et al. (2006) investigated heat-pressed lithium-disilicate glass-ceramic crowns (Empress 2) luted with either adhesive polymerizing cements or glass-ionomer cement. Sufficient tooth preparation height (≥3 mm) and a taper of a 6–10° were used as pre-requisites for cementation with glass-ionomer cement. No fracture of the framework occurred in both groups of glass-ceramic crowns after a 5-year period of clinical service. However, this study was not a randomized clinical trial. Even if it is stated that adhesive cementation reduces the need for macroretentive preparation for crowns, some restrictions in application of less retentive preparation designs were detected in clinical long-term studies [Bindl et al. 2005].

Oxide-ceramic single-unit FDPs

Oxide ceramics such as densely sintered pure alumina or partially stabilized zirconia exhibit significantly higher flexural
strengths than those of glass-ceramics. Therefore, the influence of cementation mode on the strength of the restoration seems to be diminished [Bindl et al. 2006]. In addition, one in vitro study stated that the use of a composite resin cement [Panavia F 2.0] with a bonding agent [ED Primer A&B] did not yield higher retention of zirconium oxide ceramic crowns compared with a resin-modified glass-ionomer cement [Relio × Luting] or a self-etch polymerizing resin cement [Relio × Unicem] [Palacios et al. 2006]. Similar long-term clinical results were reported by Galindo et al. [2006] for 135 single crowns with the same system. Owing to one crown fracture, the cumulative survival was rated as 99% after 5 and 7 years. This clinical success was achieved irrespective of the tooth position, tooth vitality, the preparation margin, and the cement medium used, either being a resin composite or glass-ionomer cement.

Based on these findings, it can be concluded that all-ceramic crowns made of densely sintered pure alumina represent a predictable esthetic type of restoration in the anterior and posterior region. The cementation mode, either adhesive or conventional, could be selected depending on the individual clinical situation considering the preparation design, tooth position, and geometry [Hagmann et al. 2006].

All-ceramic multiple-unit FDPs

Glass-ceramic three-unit FDPs

Kinnen et al. [2006] investigated heat-pressed lithium-disilicate glass-ceramic three-unit FDPs [Empress 2] luted with either an adhesive composite or glass-ionomer cement. As guidelines for the use of glass-ionomer cement, a minimum tooth preparation height of 3 mm and a taper of a 6–10° were used [no randomization]. Despite the high fracture rate in the experimental group [molar region], no influence of cementation mode on the survival rate was detected after a 5-year period of clinical service. In another clinical trial conducted by Marquardt & Strub [2006], 32 three-unit glass-ceramic FDPs [Empress 2] were placed exclusively with adhesive composite in the anterior and premolar regions. Six failures occurred as framework fractures [3], non-repairable partial veneer fracture [1], and biologic failures [2], resulting in a 70% survival rate in the 50-month analysis.

Oxide-ceramic multiple-unit FDPs

Tischhart et al. [2005] investigated the longevity of FDPs made of partially stabilized zirconia ceramic [DC-Zirkon] that were cemented in part with zinc phosphate cement. No fracture and retention loss occurred after an observation period of 36 months. In a prospective clinical study on the survival of zirconia posterior FDPs [Sailer et al. 2006], 46 posterior FDPs luted with two types of resin cements [Variolink, Panavia TC] were evaluated. After 36 months, seven FDPs had to be replaced because of biologic and technical problems, resulting in a survival rate of 84.8%. Chipping of the veneering material was found in 13%. Secondary caries was found in 10.9% of the FDPs, representing the major cause for replacement. This result was explained by marginal discrepancies that occurred in 50% of the investigated FDPs and was related to the prototype stage of the manufacturing technique used in the study. Obviously, the use of composite cement could not prevent microleakage and the related consequences.

As a result of the cited studies, the strength of glass-ceramics and thus the longevity could significantly be improved utilizing adhesive procedures and using supporting abutments or build-up materials with a high modulus of elasticity [Scherrer & De Rijk 1993]. When water-based cements are required, glass-ionomer cements seem to exhibit certain advantages compared with zinc phosphate cements due to the improved fit of the restorations after setting, better optical properties, and a slight adhesion to tooth tissues as well as to restorative materials [Wiskott et al. 1997; Malament & Socransky 2001]. Nonetheless, they also present a high solubility and have a low elasticity modulus. Associated with oxide ceramics, the positive influences on strength by bonding procedures and the physical properties of the abutment decrease significantly [Scherrer et al. 1996; Bindl et al. 2006]. The main indication for adhesive measures with regard to oxide ceramic FDPs should be to avoid loss of retention.

Wing-retained resin-bonded FDPs

The fundamental principle in replacing missing tooth tissues should be to restore the function and esthetics at minimal biological cost [Marinello et al. 1997]. Wing- or inlay-retained FDPs are considered advantageous to maintain both the tooth vitality and biological structures of hard dental tissues [Paszyńska et al. 1990; Edelhoff 2002a, 2002b]. In a 7.5-year survival study on resin-bonded FDPs [Creugers et al. 1992], survival rates were reported to be 75% for anterior and 44% for posterior restorations. In this study, electrotyically etched metal FDPs were found to be more retentive (78%) than perforated ones (63%). In another study by Rammelsberg et al. 1993, 141 wing-retained resin-bonded FDPs were placed under controlled conditions in a 6-year longitudinal study. The influence of location (anterior/posterior, maxilla/mandible), tooth preparation techniques (retentive/less invasive), and four different methods of metal conditioning (airblasting/electrolytic etching and/or pyrolytic/trihochemical silica coating) on the survival rate was investigated. In this study, dual-cured resin cement was used. Failures (23 of 24) were caused by loss of adhesion at the metal–cement interface. The retentive tooth preparation reduced the risk of failure to almost one-twentieth, whereas the intraoral location did not influence the survival time. The effect of silane coating on longevity was extremely positive and was not reflected by successful retainers.

Enamel-preserving preparations and the establishment of a reliable bond to both the tooth structure as well as restorative material were the most important pre-requisites for predictable long-term results. However, macroretentive preparation design can significantly improve bond strength [Burgess & McCartney 1980]. One-thousand three-hundred and ten three-unit resin-bonded FDPs were examined in a clinical study by Haastert et al. [1992]. After 5 years, 86% were still in situ. 64% did not need rebonding. The significant prognostic factors in this study were preparation, surface treatment of restoration, type of luting agent as well as the mobility of the abutments. Besimo et al. [1996] found an estimated success rate of 94% after 5 years with macroretentive preparations in the form of boxes and grooves. Behr et al. [1998] found in a clinical long-term study on 120 resin-bonded FDPs that the survival time was determined mainly by the preparation technique. Also in this study dual-polymerized resin cement was used. Strict preparation
of seating grooves and pin holes resulted in a 95% survival rate after 10 years [Kaplan–Meier estimation]. Without retention, the risk of failure increased by a factor of 3.7. In a 10-year follow-up, Audenino et al. [2006] estimated a survival probability until the first debonding or failure as 85% after 5 years and 71% after 10 years. In this study, the use of rubber dam during cementation reduced the risk of debonding. Preparation design (axial grooves or boxes, preferably on proximal surfaces), type of metallic alloy, conditioning the cementation surfaces [see the review by Özcan et al. 1998], insulation during cementation, type of cement, number of abutments, and finally the number of missing teeth included all play roles in clinical success [Kerschbaum et al. 1988].

**Inlay-retained resin-bonded FDPs**

Inlay-retained FDPs fabricated by metal alloy and placed with water-based cements are considered as an intermediate stage before starting complete crown-retained FDPs at a later stage [Eichner 1982]. This aspect must be taken into account in view of the higher rate of failure compared with FDPs retained by complete crowns. Inlay-retained FDPs made of gold alloys, which were placed using water-based cements, demonstrated a failure rate between 28.1% after an average period of 9 years of service [Sobkowiak 1981] and 46.4% after a period of 2.5–9 years of service [Bauer 1967]. Secondary marginal caries and loss of retention were recorded as the main causes of failure [Sobkowiak 1981]. After 10 years in situ, the secondary caries rate under single inlay restorations was 7% higher than under single full-crown restorations [Kerschbaum & Voß 1981]. This rate does not include the development of new carious lesions. Erpenstein & Diedrich [1977] found new carious lesions, which did not develop as a consequence of secondary caries, on the remaining tooth surface in 6.1% of teeth restored with partial crowns. The increased susceptibility to caries, therefore, is a clear contraindication for this type of restoration. The following factors are considered to be responsible for the loss of retention: mobility of the abutment teeth because of elastic jaw deformation [Marx 1967], loosening of teeth because of periodontal factors, and inadequate tooth preparation [Eichner 1982].

Additional adhesive support provided by mechanical retention will help to prevent the early loss of retention [Gardner 1991]. Specific adhesion systems used on alloy surfaces [Marx 1987] and the tooth structure [Barkmeier et al. 1986] have led to successful results for wing-retained resin-bonded FDPs for a number of years [Besimo et al. 1996; Marinello et al. 1997]. In a clinical study, where adhesive cementation was used, inlay-retained FDPs fabricated from high gold alloys demonstrated a failure rate of 3.9% after 5 years [Stokholm & Isidor 1996]. As reliable adhesive bond can be generated to ceramic materials [Edelhoff & Marx 1995; Rem & Strub 1998], a similar positive influence of adhesion could be expected in bonded ceramic inlay-retained FDPs.

Sorensen et al. [1999] claimed that adhesive techniques could only be used successfully in conjunction with resin-bonded inlay-retained FDPs, when retentive elements are provided. This clinical study on resin-bonded FDPs on teeth without retentive features or slight preparations resulted in 10.5% loss of retention after only 4 months [Sorensen et al. 1999].

**Implant-supported FDPs**

Implants as abutments offer the additional option of screw-retained FDPs. Besides numerous advantages with regard to an additional retentive function and the option of removal, the main drawback is caused by screw access holes. Placed at the occlusal surface, the esthetics and function (occlusion) can be compromised [Hebel & Gajjar 1997]. A higher potential of screw loosening and stress introduction associated with screw-retained implant-supported FDPs was reported [Brägger et al. 2005; Heckmann et al. 2006]. Cemented implant-supported FDPs, offer better handling characteristics, the reduction of microleakage, increased esthetics and function as well as the reduction of stress concentration by passive fit [Heinemann et al. 2006; Karl et al. 2006]. Specific guidelines, comparable with those for abutment tooth preparation, were given for the abutment design to create durable retention of the implant-supported FDP [Bernal et al. 2003]. For splinted multi- and single-unit implant-supported FDPs water-based as well as polymerizing cements could be used [Heinemann et al. 2006; Karl et al. 2006]. The position of the crown margin should simplify excess removal of the cement [Hebel & Gajjar 1997; Wolfart et al. 2006]. Zarone et al. [2007] found in an *in vitro* study a stronger implant–prosthetic connection in cemented restorations than in screw-retained single crowns. In an experimental study in Beagle dogs comparing screw- vs. cement-implant-retained restorations Assenza et al. [2005] reported, after 12 months, that eight [27%] loosened screws were present in screw-retained FDPs, whereas no abutment loosening was observed in cemented restorations. However, zinc oxide-based temporary cements can increase the risk of retention loss [Akashi et al. 2002; Naert et al. 2001; Palmer et al. 2005; Heinemann et al. 2006]. In another retrospective study by Preisek & Tsolkia [2004], cement- and screw-retained implant-supported prostheses were observed up to 10 years of follow-up. Screw- and cement-retained prostheses were found to be valuable options in implant prosthodontics. In this study, no accidental dislodgment of any prosthesis occurred.

In a clinical study, 86 anterior all-ceramic alumina single-unit FDPs were placed either on natural teeth or implants using a resin-modified glass ionomer cement [Zarone et al. 2005]. The evaluation was conducted after a 48-month period of clinical service. For crowns supported by natural tooth, a success rate of 100% and for implant-supported abutments a success rate of 98.3% was calculated. Within the limitations of this study, it was concluded that all-ceramic crowns fabricated by densely sintered alumina ceramic proved to be a reliable therapeutic choice for the restoration of anterior teeth on both natural and implant-supported abutments. The resin-modified glass ionomer cement appeared to be a reliable luting agent. In a randomized, prospective clinical trial, the clinical performance of two- to five-unit implant-supported all-ceramic reconstructions cemented with zinc phosphate cement was evaluated [Larsson et al. 2006]. Early 12-month results suggested that all-ceramic implant-supported FDPs of two to five units could be considered as a treatment alternative. In a 4-year prospective clinical study on single-tooth implant restoration, Vigolo et al. [2004] found a cumulative implant success rate of 100%. [200]
No differences between screw- or cement-retained implants in terms of peri-implant marginal bone or peri-implant soft tissue situation could be detected.

Discussion

Based on the literature review and the authors’ own expertise, expectations from the performance of the cement in terms of retention should be confined mainly within the preparation type and the material from which the restoration is made of. Although many factors come into play when choosing the cement, the mechanical properties of the prepared tooth still dominate for the retention especially when water based cements would be used. Dislodgement of single-unit or multiple-unit FDPs luted with water-based cements can be employed when the coronal height of the preparation is more than 3 mm, the angle of convergence is established between $4^\circ$ and $10^\circ$, as well as when the final preparation is performed using coarse diamond burs. When the coronal height is not sufficient or the preparation is overtapered ($>10^\circ$ angle of convergence), the core geometry could be idealized with the adhesive resin-based core materials and additional macrotentations on the existing dental tissues for contour corrections. In this case, water-based cements can be used. Owing to easy handling of the water-based cements and more favorable properties as opposed to the polymerizing ones, it can be chosen especially in situations where the preparation finish lines are subgingival, crevicular fluid cannot be perfectly controlled, or when a complete dry environment cannot be established. The use of polymerizing cements in such situations may then led to an impairment in the hybrid layer.

One of the determinants of the choice between water-based or polymerizing cements is the concern of microleakage and eventually secondary caries on the dental tissues underneath the FDP. Water-based cements are more prone to solubility than resin-based cements. An ideal fit of the restoration should be one of the major tasks of the clinicians and the dental technicians, especially for restorations that are conventionally cemented. Nonetheless, in that respect polymerizing cements offer more forgiving properties.

Adhesive cementation is appropriate if the location of the preparation margin permits absolute isolation with a rubber dam or when it is located supragingivaly. The adhesive cementation technique should be, however, preferred in the presence of a short clinical crown ($<3$ mm tooth height) and an angle of convergence of more than $10^\circ$, where the restorations may be more prone to loss of retention due to the reduced size of the contact surfaces and the lack of retentive walls [Wiskott et al. 1996, 1997; Cameron et al. 2006].

Esthetic considerations also play an important role associated with supragingival margins and thereby the choice of cements. In exceptional cases, partial isolation and a retraction cord without impregnation could be used instead of complete isolation. Water-based cements, using for instance, glass-ionomer cement could be preferred if the patient is known to be allergic to any of the ingredients present in adhesive bonding agents, if suboptimal periodontal conditions are present, or when visibility of the working field is poor. The basic requirements for water-based cements are an adequate marginal fit ($<100\mu m$), tooth preparations that exhibit only a slight taper of $4–10^\circ$ as well as rather long clinical crowns ($>3$ mm) that provide a large rough contact surface to prevent the loss of retention [Phillips et al. 1987; Kern et al. 1993; Goodacre et al. 2001]. The best retention method for full-coverage FDPs could be achieved with tooth preparations ground with coarse diamonds and cemented with Panavia 21 cement [Tuntiprawon 1999].

Polymerizing cements offer a wide plethora of colors with which the end result of the restorations can even be manipulated [Paul et al. 1996]. This is particularly important for anterior ceramic veneers where high esthetic is demanded.

The choice of polymerizing cements is obligatory for ceramic veneers, inlays, and onlays. The influence of adhesive cementation on increasing fracture strength of the silica-based ceramic restorations had been proven in in vitro and in vivo studies [Scherrer et al. 1996; Malament & So-cransky 1999a, 1999b]. However, to avoid a higher incidence of microleakage it is advantageous to confine the preparation margins within the enamel shell [Friedman 1998; Federlin et al. 2005]. Marginal defects of ceramic laminate veneers were especially noted at locations where the restoration ended in existing composite fillings [Karlsson et al. 1992; Peumans et al. 2004].

With the introduction of high-strength oxide ceramics, the compulsory application of adhesive cementation is diminished. Reinforced ceramics do not seem to require adhesive cementation for ceramic strengthening purposes unless of course, the fit of the restorations is ideal. The main indication for adhesive measures should be the avoidance of loss of retention and the improvement of esthetics. In situations where collarless cores are fabricated, adhesive cementation seems to be advantageous for oxide ceramics due to the tooth-like color and improved light transmission of the adhesive cements [Hagmann et al. 2006]. Furthermore, early reports on more user-friendly self-etching cements are promising [Piwowarczyk et al. 2005], but clinical long-term data are not available to date.

For wing-retained FDPs, the choice of dual-polymerizing resin-cements increased the survival of such restorations. However, the results from the literature all favor additional support of adhesive measures by the preparation of grooves and pin holes for the metal wings. These additional macroretentions decreased the risk of failure by a factor from 3.7 to 20 [Rammelsberg et al. 1993; Behr et al. 1998].

In all aspects of adhesive cementation, the right surface conditioning both for the dental tissues and the cementation surface of the restorations should be performed accordingly. In adhesive applications, tooth–cement–material unity could be achieved with the most suitable conditioning method for each group of dental materials, namely metals, ceramics, or polymers [Edelhoff & Marx 1995; Kern & Strub 1998; Kern & Wegenner 1998; Özcan et al. 1998]. This issue is particularly important in minimally invasive applications where retention of the restoration does not rely on mechanical retention. Type of tooth substrate, enamel or dentin, seems to have an impact on the type of failure. Failures associated with wing-retained resin-bonded FDPs bonded to the enamel were caused mainly by loss of adhesion at the metal–cement interface [Rammelsberg et al. 1993]. In clinical
long-term studies with adhesively luted glass-ceramic crowns, loss of retention was caused mainly by loss of adhesion at the dentin–resin interface [Kimmen et al. 2006]. These in vivo observations were confirmed by an in vitro study on the marginal integrity of feldspathic partial ceramic crowns, in which the dentin-luting material interface, in general, showed higher percentages of compromised adhesion than enamel– and ceramic–luting material interfaces [Federlin et al. 2005]. If this unity is not achieved, the bonded interface would result in detachment of one layer from the other and eventually dislodgement of the restoration. A growing number of efforts are being made to optimize the resin cement adhesion on several ceramic, metal, or polymers using adhesive technologies. Clinicians should be up to date with these developments when they aim for elegant adhesive cementation.

In many applications of FDPs such as implants, resin-bonded, or metal-ceramic restorations, the dental literature lacks split-mouth randomized clinical trials. Future study designs should consider this missing information. In conclusion, clinicians should consider all confounding factors when deciding between water-based or polymerizing cements. The selection of adequate cementation mode is affected by the restoration (i.e., restorative material properties, marginal fit, type of restoration, surface treatment), the properties of the cement (i.e., viscosity, biocompatibility, adhesive potential, solubility, water uptake, color stability, wear resistance, working and setting characteristics, sealing ability, optical properties, radio-opacity) as well as various clinical covariables such as occlusion, preparation design (retentive, non-retentive), moisture control, type of build-up material, type of supporting abutment (natural tooth structure: enamel, dentin, cementum), or implant abutment (titanium, oxide ceramic), mobility of abutment, surface roughness, margin location (enamel, dentin, cementum), tooth location, and degree of tooth destruction.

References


Erpenstein, H. & Diedrich, P. (1977) Follow-up studies on the caries susceptibility and gingival