CONVENTIONAL, MICROFILLED AND HYBRID COMPOSITE RESINS: LABORATORY AND CLINICAL EVALUATIONS

Jan W V van Dijken

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Abstract

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Three types of composite resins, classified as conventional, microfilled and hybrid resins were compared with respect to surface characteristics, effect on the gingival margin, marginal adaptation and clinical durability in anterior cavities.

The surface characteristics were studied in *in vitro* systems by means of scanning electron microscopy. Fillings prepared *in vivo* were evaluated regarding surface characteristics, marginal conditions, color stability and the effect on the development of gingivitis and caries.

Microfilled resins were superior to the conventional and hybrid composites with regard to the possibility of obtaining and retaining a smooth surface. The number of porosities varied greatly between the composites investigated and could not be related to the type or curing method used in their manufacture. Marginal defects in the form of chip fractures and fractures in the resin parallel to the resin/enamel border were seen more frequently in the microfilled composite fillings than in the conventional and hybrid resins. The severity of the defects increased with time.

There was a great variation in clinical behaviour within each resin group. The difference in surface characteristics between the three composites did not result in clinically measurable differences in amount of plaque on and degree of gingivitis around the composite fillings neither during a period of normal home care nor during an experimental gingivitis period. Recurrent caries was the major single reason for replacement. Patients with a greater number of caries risk factors clearly showed a higher caries increment, especially around composite fillings. The shortcomings of the three composite resin types indicate that no material as yet meets the demands of an all purpose material.

*Key words:* composite resin, caries, gingivitis.
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PREFACE

This thesis is based on the following papers, which will be referred to by their Roman numerals.


NOMENCLATURE OF COMPOSITE RESINS

The nomenclature for the resin materials used in dentistry is complex and somewhat illogical. The aim of the following section is to clarify some expressions.

A proper definition of a composite material is "a material system composed of a mixture of two or more macro constituents that differ in form and that are essentially insoluble in one another" (Glenn 1982). According to this definition, many materials used in dentistry can be considered as composites. Glass ionomer cements for example consist of reacted particles of glass connected by a matrix of calcium and aluminium polyacrylate chains. In dentistry the term composite resin has been reserved for the methacrylate based resin materials which are polymerized by free radical initiated polymerization and reinforced with at least 50 vol% (=60 wt%) of filler particles. The selection of 50% filler is arbitrary (Glenn 1982) and some of the microfilled resins have been marketed as composites despite a filler content < 50 vol%. In this thesis the term composite is also used for these resins.

Three groups of composites can be identified according to their filler content.

Conventional composite resins, the first generation of composites, contain relatively large filler (macrofiller) particles such as ground quartz, borosilicate glass or lithium aluminium glass. Most particles range in size 20-50 μm, and the total range is 0.1-150 μm.

Microfilled composites contain so called microfine filler particles of pyrolytic silica (SiO₂), in the range of 0.007-0.14 μm with a mean of 0.04 μm. They were developed in 1974 and were marketed at the end of the 1970s.

Hybrid composites. According to Websters dictionary a hybrid is "anything of mixed origin". In dentistry the term hybrid composite is used for resins containing a blend of macrofiller particles and microfine pyrolictic silica particles.
INTRODUCTION

Background

The first tooth-colored filling material available on the market was silicate cement introduced in 1904 by Steinbock and Richter (Hendriks 1985). The popularity of the silicate cements was related to their high compressive strength - they were among the strongest inorganic cements known at that time - their physical and esthetic properties, and their slow release of fluoride. The fluoride content helped to protect adjacent tooth enamel from caries and was of definite therapeutic value.

Many of the silicate restorations, were successful and clinical life times have been reported of up to 20 years, with an average of 4.5 years (Bowen 1968, Robinson 1971). However, there were disadvantages with the silicate cements which prompted a search for a replacement material which led to the development of the polymeric anterior restorative resins.

Early, attempts were made to use resins as a restorative material by employing methylmethacrylate polymers (MMA), intended for heat-curing crown and bridge applications. The polymer was mixed with a monomer in order to form a material which could be packed into the tooth cavity. The first self-curing dental resins were based on a patent taken out by Kulzer (1943). The methylmethacrylate was hardened at room temperature by bringing a tertiary amine as accelerator into contact with benzoyl peroxide as the catalyst. A redox reaction thus started the polymerization of the monomer (Bauer 1949, Salisbury 1943, 1950).

Cold curing resins were widely used from the beginning of the 1950s in Class III and Class V restorations and in Class IV restorations with supplemental retention provided by pins and later by the acid-etch technique. Because of the apparent ease with which they could be manipulated, the dental market very soon became overloaded with synthetic materials. However, a number of problems were quickly manifested clinically. The major problem was a shrinkage of up to 10% in volume during polymerization. The shrinkage could not be
compensated for by subsequent watersorption. The resulting marginal leakage allowed the ingress of bacteria leading to discoloration and pulpal inflammation. Recurrent caries was frequently observed around these restorations (Caul and Schoonover 1953, Hedegård 1955). The brush technique introduced for successive applications of the resin (Nealon 1952) afforded a slight improvement but did not solve the problems of the self-curing resins. The shortcomings of the unfilled resins led to the continued use of the silicate cements.

The idea of improving the cold curing resins by mixing them with inorganic filler particles to form composite resins dates back to 1951 (Knock and Glenn). Paffenberger et al suggested in 1953 that appropriate fillers could reduce the polymerization shrinkage and the thermal expansion of the dental resins. The objective was to maximize the ratio of reinforcing filler to resin.

Pioneering work was performed by Bowen (1956) at the National Bureau of Standards in Washington. In the search for a better resin a modification of the epoxy resins, known in dentistry as "Bowens resin" or BIS-GMA resin, was introduced in 1962. This resin which was a reaction product of bisphenol A and glycidyl methacrylate could be cured intraorally by a chemical catalysator (Bowen 1962, 1963, 1965). BIS-GMA forms a resin with less polymerization shrinkage and higher viscosity than MMA (Bowen 1962, 1963). To facilitate the insertion of the resin into cavities the viscosity was reduced by the addition of more liquid dimethacrylates of lower molecular weight. However, too high a concentration led to undesirable polymerization shrinkage. It is noteworthy that until very recently almost all dental composites were based on the BIS-GMA resin. Bowen combined silica powder with the BIS-GMA monomer and achieved a highly loaded (around 70%) restorative. He suggested in 1964 an uneven size distribution for the fillers in order to get maximum packing of the inorganic filler.

The addition of filler particles was an improvement. The composites exhibited increased compressive and tensile strength as well as an increased modulus of elasticity and hardness. They also absorbed less water and had a lower coefficient of thermal expansion and less polymerization shrinkage (Glenn 1982). The superior qualities of the composites in comparison with the unfilled resins, at least in the laboratory, led to universal acceptance of the resins in the seventies. They gradually replaced the unfilled resins and the
silicate cements. However, as clinical use increased, the disadvantages of the composites appeared in the form of poor marginal adaptation, difficulties in maintaining a polished surface, lack of adhesion to tooth structure and an esthetic appearance that did not endure.

During the 1970s, microfillers were used as reinforcing particles to obtain a more polishable resin. At the end of the 1970s hybrid composite resins were introduced which contained a blend of macro- and microfiller particles, in an attempt to combine the properties of the conventional and the microfilled materials. Other approaches aimed at improving composite resins were the introduction of finer and softer glass fillers, resins with a higher load of particles and the use of resins with porous glass (Bowen & Reed 1976, Ehrnford 1983).

A different line of development was seen at the beginning of the 1970s, when a new tooth colored restorative was introduced, the glass ionomer cement (the official ISO terminology: glass polyalkenoate cement). It is by definition a composite resin but in dentistry it is not referred to as such. It was developed in an attempt to combine the successful properties of both the silicate cement and the polycarboxylate cement which was used as a lining material and for cementing crowns and bridges. The new cement had the strength and almost the translucency of the dental silicate cements, and showed a greater resistance to acid attack. It also appeared to have the adhesive and biocompatible properties of the polycarboxylate cements. The filler is also an aluminosilica glass, containing fluoride which is released from the set cement (Forsten 1977b). It should be as effective as silicate cement in inhibiting recurrent caries (van Dijken 1986).

Composition and curing method

A dental composite consists basically of three parts: the organic matrix, the coupling agent and the inorganic filler.

Matrix: The major monomer component used in most of the commercial composite resins is the BIS-GMA or modifications of the molecule. Some composites contain aliphatic or aromatic urethane diacrylate as major
monomer component. Diluent monomers are used to facilitate the handling of the material (Lambrechts 1983, Ruyter 1985).

**Filler:** Conventional composite resins contained between 55-60 vol% (=70 wt%) filler particles, while the first microfilled composites had a filler load in the range of 17-40 vol% (30-55 wt%). Most hybrid composite materials contained a total of 75-85 wt% filler of which 7% was pyrolitic silica.

The inorganic filler of most hybrid resins and some conventional composites is a glass made radiopaque by incorporation of barium or strontium. Pyrolitic silica and the traditional quartz filler particles will not make the material radiopaque. During the 1980s, hybrid composites for posterior use were introduced, containing smaller filler particles with an average size of 2-5 μm.

**Initiator - activator:** Composite resins can be divided into chemically cured and light-cured resins. The former is a two-component system and the latter a one-component system (Buonocore and Davila 1973). In a two-component system the paste of the monomer and filler is divided into two portions; one containing an initiator and the other an activator. The reaction starts when the two components are mixed. The most commonly used initiator-activator system is benzoyl peroxide activated by a tertiary aromatic amine. Free radicals are generated and polymerization is initiated. Simultaneously a bond is formed between the particles and the matrix. In a one-component system the polymerization is initiated through the absorption of light by a photo-initiator. In contrast to the chemically cured systems, the rate of reaction is not uniform in a light-cured material. It is fastest near the illuminated surface and becomes progressively slower in the deeper layers (Cook 1983). Although originally developed as UV light-polymerized materials (absorption spectra ca 365 nm), the possible health problems associated with UV radiation (Ham 1983, Pitts 1981) resulted in the development and increased use of visible light-cured materials. In these composites, blue light is absorbed by an alpha-diketone, usually camphorquinone (absorption peak at 470 nm) (Ruyter 1985). In the excited state it reacts with an amine reducing agent to produce the free radicals. This starts a series of reactions which leads to polymerization.
The light-cured materials have a longer manipulation time and require no mixing. This may result in fewer porosities and better color stability since there is no amine accelerator present. The wavelength and the intensity of the light used to cure the resin are important for the result (Kilian 1981). Large variations among different visible light sources have been shown (Newman 1983). The light-cured resins have disadvantages that chemically cured resins do not have. The materials are sensitive to light and polymerization can begin even under an operation light. Additional equipment is necessary and there is a limited cure depth. Incomplete polymerization in the inner part of the restoration may lead to retention failures, pulp irritation, tissue reactions and discoloration (Stanley et al 1972, Spångberg et al 1973). Greater curing depths are obtained with macrofilled than with microfilled composites (Ruyter 1982). For the UV-light cured composites, the practically realizable depth of curing was approximately 2 mm. Therefore the use of a layering technique was advocated (Buonocore and Davila 1973). Because the resin is more transparent to visible light which is more intense, these materials attain a depth of cure of 3-5 mm (Cook 1983). Because of factors as accessibility to the light source and direction of the light the depth of cure is clinically mostly less than that achieved under ideal laboratory conditions.

Inhibitor: Inhibitors are added to the filler-monomer mixture to ensure that the composite has an adequate shelf-life. One of the most widely used inhibitors is hydroquinone (Lambrechts 1983).

Filler-resin bond: To achieve a bond between the polymer and the filler during polymerization either a semi-porous filler, giving a mechanical bond (Bowen and Reed 1976, Ehrnford 1983) or a silane layer on the filler particles giving a chemical bond (Bowen 1962, 1963) is used. The latter is the most commonly used bond in the commercial composites. Söderholm (1984) showed debonding of the silane bond due to hydrolytic degeneration or slow crack growth and suggested that this could become a major clinical problem.
Properties of composite resins

*Polymerization shrinkage*

One major drawback of polymeric materials is the setting shrinkage which allows a gap to form between the cavity wall and the restoration. This permits microleakage of oral fluids containing ions and bacterial toxins, giving rise to pulpal reactions, staining of restoration margins and recurrent caries.

The incorporation of filler particles in the resins reduced the level of shrinkage, but various composite materials still exhibit shrinkage of 1.67 to 5.68 vol % (Goldman 1983). Microfilled composite resins which contain a relatively high percentage of organic matrix exhibit a larger polymerization shrinkage than the macrofilled composites.

The photocured materials contract towards the outer surfaces of the restoration closest to the light source in contrast to the chemically cured resins in which shrinkage occurs towards the center of the material. The shrinkage is also dependent on e.g. the diluent monomer content (Asmussen 1975).

*Polymerization defects*

Polymerization shrinkage obviously leads to the promotion of a marginal gap unless a bond is formed between the resin and the tooth structure. When the bond is strong enough, the contraction forces developed during polymerization can cause internal stresses in the composite resin, the enamel or at the material/enamel border. When the internal stress exceeds the strength of the bond between tooth and resin i.e. the cohesive strength, then cracks in the enamel, cohesive failures in the resin, and dentinal gap formation occur (Asmussen & Jørgensen 1972, Jørgensen et al 1975, Öilo & Jørgensen 1977, Fan 1985, van Dijken & Höristedt 1986, 1987a). Post-operative sensitivity - observed in connection with larger, mostly posterior restorations - is probably a consequence of contraction forces.
The recently introduced technique of incremental polymerization of resin fillings and the use of dentin bonding agents did not reduce the shrinkage, measured as a reduction in microleakage and gap formation (Forsten 1984, Jensen and Chan 1985, van Dijken & Hörstedt 1986, 1987a). To reduce the marginal gap - especially in the non-etched cervical part of the cavity - the application of a low-viscous resin at the opening of the gap has been suggested (Brännström 1984). Another way of reducing the polymerization shrinkage is by using composite inlays made either directly or indirectly, polymerized in an oven at 120°C and cemented with a resin.

Another major problem is incomplete polymerization. Between 25 and 60 per cent of the dimethacrylate molecules remain unreacted in the composite resin, resulting in a poorly connecting network (Ruyter & Svendsen 1978, Ruyter & Öysaed 1982, Vankerckhoven et al 1982, Asmussen 1982). These authors also showed that a low degree of polymerization produces low tensile, transverse and compressive strengths, high creep values and low surface hardness. The methacrylate conversion in composite resins is dependant on the polymerization temperature and the concentration and chemical nature of the initiator and accelerator (Asmussen 1982). A maximal conversion of reactive groups is seen in the composite inlays cured at a temperature of 120°C. An additional factor in a chemically activated system is the adequacy of the mixing of the two pastes. The entrapment of air bubbles during mixing produces an important matrix defect reported by several investigators (Forsten 1977a, Skjörland et al 1982, Reinhardt et al 1982). The porosities are reported to constitute up to 28% of the volume. Porosities severely impair surface morphology and wear resistance (Wilder et al 1984). Photo-activated systems mostly contain fewer porosities than chemically activated systems (Reinhardt et al 1982, Gotfredsen et al 1983).

In a photo-activated system, the light intensity, spectral distribution and duration of curing time are influential factors on the degree of polymerization, which decreased, with increased distance from the top surface (Ruyter & Öysaed 1982).

The degree of polymerization therefore is an important factor in the clinical performance of resin restorations, especially in wear characteristics (McKinney & Wu 1982, de Rijk et al 1984), creep (Ruyter & Öysaed 1982) and color stability (Ruyter & Svendsen 1978).
However, residual photo-initiator and amine accelerator (Asmussen 1983) or their by-products are primarily responsible for the color instability of composite resins.

**Water absorption**

All composite resins absorb water from the oral environment and undergo hygroscopic expansion (Asmussen & Jørgensen 1972, Bowen et al 1982). Asmussen & Jørgensen (1972), showed in vitro that the marginal gap around composite restorations could be closed by the hygroscopic expansion of the filling material in non-etched cavities. The water molecules diffuse through the open spaces between the polymer molecules. The polymer chains are pressed apart by the uptake of water and the degree of hydratization. The water uptake is restricted by the extent of cross-linking. Porosities enclosed in the material are also filled with water and the total water uptake represents a linear expansion of 0.4-0.8 per cent. The swelling process compensates partly for the setting contraction. Microfilled resins show higher levels of water absorption than conventional composites. It has been suggested that a hydrolytic degradation of the filler-matrix bond in dental composites (Söderholm 1984) is a negative impact of water absorption.

**Clinical consequences of the properties**

The composition of the materials and the properties, mainly with respect to volumetric changes, have consequences for the clinical longevity and biocompatibility of the composite restorations.

**Surface characteristics**

The structure of the polished surface of the polymerized material is strongly dependent on the size, packing and hardness of the filler in relation to the resin matrix. The smooth surface obtained under the strip cannot be maintained when the restorations are finished
Surface roughness following polishing is also a function of the abrasive nature of the polishing agent. Most finishing techniques produced rough surfaces on conventional composites (Glantz & Larsson 1972, Dennison and Craig 1972, Gray and Gavin 1975). The softer resin matrix is easily removed leaving the hard glass or quartz particles protruding. A similar surface can be expected to emerge after toothbrushing (Asmussen 1979). A rough surface can only be made smooth again temporarily by application of a glaze or veneer on the finished surface (Heath & Wilson 1976, Calatrava et al 1976, Garman et al 1977, Mc Cabe & Caddick 1978, Williams et al 1978, Lambrechts and Vanherle 1983). Several authors have reported that rough surfaces favor the accumulation and retention of debris and bacterial plaque (Gildenhuys & Stallard 1975, Mörmann et al 1974, Smales et al 1979). This can promote gingivitis, recurrent caries and staining of the fillings (von der Fehr et al 1970, Larato 1972, Smales 1975, Smales et al 1979).

Because the filler particles of microfilled composites are smaller than the wavelength of visible light, the composites looked like a homogeneous material. The manufacturers stated that these materials are not liable to extrinsic discoloration and that plaque accumulation is minimal.

**Adaptation to the cavity wall**

The maintenance of a tight connection between a filling and the cavity wall is dependant on the balance between shrinkage and the strength of bonding between the material and the cavity wall. The establishment of a strong permanent bond between a restorative and the hard dental tissues is highly desirable. An effective bonding may prevent microleakage and eliminate the need for retentive undercuts. This reduces the risk of pulp damage, marginal discoloration and recurrent caries.

The nature of a bond can be mechanical or chemical or a combination of both. A mechanical bond is formed by the penetration of the resin into the micro-irregularities of an enamel etched by means of the technique introduced by Buonocore (1955). Buonocore used 85% phosphoric acid to etch the enamel prior to the use of acrylic restorative materials. Silverstone et al (1975) showed that the most
even etching patterns were found when solutions of 30-40% phosphoric acid were applied for 60 seconds. Recently, several investigators have shown that etching for 15-20 seconds resulted in proper sealing conditions (Nordenvall 1981, van Dijken and Hörstedt 1986).

Initially, enamel etching was made in the placement of pit and fissure sealants. The application expanded to include Class III, IV and V restorations, veneering of hypoplasia and other cosmetic bonding procedures including diastema closure and labial veneering, bonding of orthodontic brackets, periodontal splinting and temporary bridges.

Microleakage

Marginal permeability at the interface between restoration and tooth has been a focus of interest amongst dental investigators for nearly 75 years. The passage of fluid, bacteria, molecules or ions in the space between a restorative material and a prepared cavity wall of a tooth has been called marginal percolation, marginal leakage and microleakage (Going 1972, Kidd 1976a, Browne & Tobias 1986). With the possible exception of when polycarboxylate- and glass ionomer cements are used, there is always a gap between the material and the cavity wall, caused partly by the contraction of the mass of material during the setting procedure and partly because the material does not adhere to the tooth (Asmussen and Jörgensen 1972, Barnes 1977, van Dijken and Hörstedt 1986). The microleakage can be related to the properties of the filling material itself or be dependent on the procedures used for cavity treatment and handling of the material.

Several methods can be used to test the sealing properties of restorations. Harper (1912) used air pressure and Fraser (1929), Rose et al (1955), Mårtensen et al (1965), Brännström & Nyborg (1971), Browne et al (1983) for example used bacterial penetration as a qualitative measure of tightness. However, the penetration of dyes and radioactive isotopes has been most frequently studied (e.g. Brown et al 1962, Christens & Mitchell 1966, Going et al 1960, Forsten 1978, 1982, van Dijken 1980). The susceptibility of the gap to artificial caries was studied in an acidified gel system (Kidd 1976b, Grieve 1973, Grieve & Jones 1980) and the gap itself was observed by means of
direct visualization with light microscopy and scanning electron microscopy (Asmussen & Jörgensen 1972, van Dijken and Hörstedt 1986). Unfortunately, there are considerable variations in the results obtained with the different in vitro methods used. This combined with the lack of criteria for when the sign of a gap is of clinical relevance makes an observation made using an in vitro method uncertain (Shortall 1982, Kidd 1985).

Microleakage predisposes the tooth to pulpal irritation, thermal sensitivity, marginal discoloration and recurrent caries. Earlier studies concluded that pulpal inflammation under acrylic resin restorations and silicate cement fillings was caused by chemical irritation emanating from the materials (Browne & Tobias 1986). However, Zander (1951, 1959) and Mitchell (1959) proposed that inflammation was due to bacterial ingrowth in the space between cavity wall and restoration. From in vivo experiments, it appeared that the leakage of fluid was accompanied by bacterial growth, unless the material placed in the cavity had persistent antibacterial properties. The presence of microorganisms has been demonstrated in the space between the filling and the cavity wall in cavities filled with different restorative materials. Numerous investigations during the last 20 years have shown that bacterial irritation is the main cause of pulpal damage beneath silicates, acrylic resins, composite resins and other restorative materials (e.g. Brännström & Nyborg 1969, 1971, 1974, Qvist 1975, 1980, Brännström & Nordenvall 1978, Brännström et al 1979, Mejare et al 1979, Tobias et al 1981, 1982, Bergenholtz et al 1982, Heys et al 1985, Leidal & Eriksen 1985). Through the reduction or elimination of bacterial leakage pulpal inflammation has been reduced or prevented beneath cavities filled with silicates and composites (Skogedal & Eriksen 1976, Brännström & Nordenvall 1978, Tobias et al 1982). Jörgensen et al (1976) suggested that mechanical forces in the oral environment promote leakage. Qvist (1983) demonstrated greater bacterial leakage around composite fillings in teeth in functional occlusion than in similar cavities in unopposed teeth. She concluded that functional stress on teeth was the most important factor for penetration of bacteria through leakage.
Techniques to reduce microleakage

Galan et al (1976) and van Dijken (1980) found that etching the enamel wall reduced but did not eliminate marginal leakage around composites. Eriksen & Buonocore (1976) demonstrated that leakage was only eliminated when the cavity margins were bevelled prior to etching or when the resin was extended into the etched surface enamel adjacent to the cavity margin. Most studies of microleakage around composite fillings placed with the acid-etch technique, dealt with restorations in which the margins were entirely within the enamel rather than with restorations that contained margins both in enamel and cementum or dentin. Since tags of resin can only be achieved when the enamel has been etched in the long axis of the prisms, bevelling of cavity margins prior to etching has been generally accepted. It might be observed that the subsurface of the enamel exposed by the bevelling etches more readily than surface enamel. This is one reason why long etching times are unnecessary. The bevel allows a gradation of color as the composite resin becomes progressively thinner towards the tooth surface (Groper 1971, Roberts & Moffa 1972, Hill & Soetopo 1977) and decreases the occurrence of enamel fractures (Öilo & Jörgensen 1977).

Several factors adversely impair the penetration of resin into enamel thus contributing to poor bonding. These include rubbing the enamel during conditioning, incomplete removal of the etching agent and reaction products, contamination of the etched enamel with saliva, blood, gingival fluid or precipitation of water vapor from exhaled air (c.f. van Dijken and Hörstedt 1987b).

Resin viscosity has also been thought to affect resin penetration (Jacobsen et al 1977). There is a controversy over whether an intermediate resin system of low viscosity, would better penetrate the acid etched enamel if used prior to placement of the composite resin. In several in vitro studies no difference was seen between tag formation from a highly viscous composite resin and from a low viscous bonding agent (Jörgensen & Shimokabe 1975, Asmussen 1977, Martin & Bryant 1984, Barnes 1977), while another study showed that the tags formed with the high viscous composite resins were shorter (Nordenvall
Some studies of bonding strength show that the low-viscous resins have little if any effect (Rider & Tanner 1977, Mitchem & Turner 1974, Raadal 1978, Prévost et al 1982) while others indicate an improvement in retention (Ortiz et al 1979, Meurman & Nevaste 1975). In some studies it was observed that the use of a bonding agent reduces microleakage (Galan et al 1976, Qvist & Qvist 1977, Brännström & Nordenvall 1978, Luscher et al 1978, Forsten 1978, van Dijken 1980, Martin & Bryant 1984) while others showed that it has no effect (Ortiz et al 1979, Retief & Wood 1981, Retief et al 1982). Microleakage was significantly greater at the cervical margins than at the occlusal margins for both conventional and microfilled resins (Retief et al 1982).

Buonocore et al (1956) also did pioneering work on the adhesion of fillings to dentin. His idea of using a bonding agent as an intermediary layer between dentin and restoration led to a considerable effort over many years to develop an effective dentinal bonding agent. Several products have become commercially available during the 1980s. In many cavities where there is no enamel available for bonding on one or more cavity walls, dentin bonding is essential for retention purposes and to prevent microleakage and pulpal irritation. Gap formation and marginal leakage is not prevented by most commercial dentin bonding agents (Forsten 1984, Welsh and Hembree 1985, Gordon et al 1986, van Dijken and Hörstedt 1986, 1987a).

At the present time, glass ionomer cements and polycarboxylate cements seem to serve best as dentin adhesive restorative material. A good adaptation to both enamel and dentin without gap formation has been shown in vivo (van Dijken 1986, 1987a).

In vitro caries

Attempts have been made to study the relationship between microleakage and caries at the tooth-filling interface. The in vitro caries technique of Silverstone (1967) was used to produce secondary caries-like lesions around restorations in extracted teeth (Kidd 1975). In this technique an acidified gelatine gel provides hydrogen ions for the carious attack on sound enamel. The microspace between filling and cavity walls allows diffusion of hydrogen ions to occur.
along the cavity walls. Kidd (1975, 1976b) showed that lesions appeared along the cavity walls in 77% of the amalgam restorations, whereas only 13% of composite restorations showed evidence of a wall lesion. On the other hand, Grieve & Jones (1980) examined marginal leakage associated with composite fillings in vitro using the same technique and demonstrated caries in 95% of the unetched cavities. Approximately 50% of the restorations in etched unbevelled cavities showed lesions, while in the bevelled and etched group virtually no caries occurred. These observations seem incompatible and Kidd (1985) claims that the in vitro models should be abandoned in favour of in vivo studies. The effect of the acid-etch technique on caries development around composite fillings was observed earlier by Eriksen & Pears (1978). They studied the histology of caries lesions generated from bacterial plaque growing in an in vitro system. The carious lesions penetrated along unetched class V restorations, which also showed bacterial leakage. However in the composites made with an acid-etch technique no bacterial leakage was seen and the carious lesion was limited to the free enamel surface.

The size of many caries-inducing microorganisms is in the order of 1 μm. Bauer and Henson (1984) stated that a space from 2-20 μm is necessary for penetration of the bacteria and for a bacterial film to form. Jörgensen and Wakumoto (1968) stated that the magnitude of the marginal defect must be approximately 50 μm in order to produce recurrent caries. The penetration of a small ion like the hydrogen ion (about 1-2 Å) in the acidified gel experiments is therefore a poor indicator of the size of the marginal gap and cannot be directly related to caries development. The clinical relevance of the wall lesions produced in vitro as a consequence of microleakage of hydrogen ions has been questioned (Kidd 1985). The in vitro studies are based on the simple diffusion of hydrogen ions along the cavity wall whereas caries formed in vivo is a function of several conditions. The oral environment therefore has a profound bearing on the success and longevity of any restoration (Goldberg et al 1981). It seems obvious that microleakage of bacteria and substrate will play an important role in the formation of recurrent caries in vivo.
Biocompatibility

The aim of biological testing is to prevent the introduction of materials with local or general biological side effects. Despite the justified need for testing so far only guidelines have been set up (ADA 1979, FDI 1980, BSI 1982, DIN 1986). In a review Mjör et al (1985) suggested that the biological testing should be carried out under three main headings: preliminary tests to obtain a toxicity profile of the material, usage tests to investigate the effect of the material in a manner identical or similar to their use in patients and antibacterial property and plaque formation tests. Mjör et al (1977) and Wennberg et al (1983) stated that many of the preliminary tests do not produce the same results as the usage tests and questioned the validity of in vitro methods for biological testing. Development of in vitro methods which more closely simulate in vivo circumstances has been advocated (Brown & Tyas 1979). The pulp test for restorative materials is the most widely accepted usage test and Wennberg et al (1983) concluded that the final biological evaluation of dental restoratives still has to be carried out in the form of pulp studies. However, the degree of pulp reaction in relation to clinical acceptability has not yet been established.

Polymerized composites contain a large amount of remaining unreacted methacrylate groups (Ruyter & Svendsen 1978, Vankerckhoven et al 1982) and many of the components in the composites are potential sensitizers (Björkner 1984, Hensten-Pettersen & Holland 1985). However, only a few allergic reactions specific to composite resins have been reported during their 20 years of use (Katz 1977, Nathanson & Lockhart 1979, Tinkelman & Tinkelman 1979, Malmgren & Medin 1981, Niinimäki et al 1983, Björkner 1984).

Composite tooth filling materials contain biologically reactive chemicals which are not bound when the material is introduced into the cavity. In cell culture tests chemically cured resins were more toxic during and immediately after polymerization than 24 h later (Wennberg et al 1983). A light-cured composite was less toxic than a chemically cured one. Composite materials caused less cell damage than silicates,
cold-curing plastics (Spångberg et al 1973) and zinc oxide eugenol cement (Mjör et al 1977, Wennberg et al 1983). The toxicity of the resin material is caused by substances leaking from the resin during the first 24 hours.

The cytotoxic effect of composite materials have mostly been evaluated in pulp studies. Pulp reactions ranged from none to slight and moderate in different reports (Brännström 1971, 1972, Bloch et al 1977, Mjör et al 1977, Heys et al 1985, Leidal and Eriksen 1985, Mjör & Wennberg 1985). None of the individual components of composite materials held on the pulpal walls of cavity preparations for 21 days caused significant pulp reactions. The average response levels did not exceed 1 on a 0-4 scale (Stanley et al 1979).

The tissue most often in contact with composite fillings is the gingiva. The toxicity per se may not be a serious factor in inducing reactions but the plaque adhesive properties may be of more importance. The few studies evaluating this kind of response are based on conventional composites. Larato (1972) and Dunkin & Chambers (1983) observed gingivitis adjacent to subgingival Class V composites, while the gingiva adjacent to non-restored surfaces was not inflamed. Blank et al (1979) on the other hand found, that such composites did not adversely affect the health of the gingiva. Skjörland (1973, 1976), Sönju and Skjörland (1976) and Dummer & Harrison (1983) found more plaque accumulation on conventional composites than on polished amalgam, silicate cement or tooth enamel.

It has been recommended earlier that the antibacterial properties of restorative materials should be assessed as part of their screening for biocompatibility (Mjör et al 1985). If bacteria found in the microspace do cause pulpal inflammation, the different antibacterial properties may explain the varying degree of pulp response. Freshly mixed materials show some degree of antibacterial activity, though the effects varied between microorganisms. Örstavik & Hensten-Pettersen (1978) showed that there was a wide variation in antibacterial properties amongst chemically cured dental composites in an in vitro system. All materials showed some degree of antibacterial activity when fresh, but the activity was strongly diminished, in several cases ceased totally, after setting and storage.
Clinical evaluations

All active testing programs on dental materials have until recently been based on evaluation of a wide variety of mechanical and chemical properties in the laboratory. These tests serve primarily as a guide for determining whether or not a dental restorative has the potential for clinical use. Until recently testing programs usually did not include requirements for clinical testing. It is now generally agreed that clinical evaluation of dental materials is essential for the final analysis of the efficiency of the materials and that standardization of clinical procedures, including the handling of the material, is necessary.

Clinical assessments can be made by direct or indirect techniques. The direct technique involves an evaluation with the patient present at the time of assessment, i.e. mirror and probe type of approach. During the 1970s the International Dental Association (FDI) adapted a direct registration system, for quality evaluations of clinical performance. In this system (Cvar & Ryge 1971) restorations were graded according to criteria describing the degree of failure at the time of examination. The criteria for the clinical evaluation of tooth colored restorations included: color matching ability, cavo-surface marginal discoloration, surface roughness, loss of anatomical form or wear, marginal adaptation and recurrent caries.

In the indirect techniques the assessments are made from replicas or some type of representation of the original filling such as clinical photographs, casts or scanning electron micrographs (Mjör et al 1985).

Earlier investigations of conventional composite resins in anterior cavities reported no or low recurrent caries frequency after 1 to 5 years. The marginal adaptation of composites was superior to that of amalgam during the first year. The composites tended to lose anatomic form sooner than amalgam and surface roughness and body discoloration occurred (Qvist et al 1980, Eames et al 1974, Osborne & Gale 1980, Smales 1975, Ulvestad 1978, Liatakus 1972, Leinfelder et al 1975, 1980, Chandler et al 1973).

Ameye et al (1981) reported that microfilled resins showed a good color stability which was comparable or sometimes superior to the
conventional resins after 18 months. Marginal adaptation was, however, not satisfactory in Class IV and V restorations. Loeys et al (1982) concluded that after 30 months microfilled resins had a higher percentage of success than the conventional composites. However, a high degree of marginal disintegration and chip fractures of microfilled resins was reported by the same group in another study (Lambrechts et al 1982). Christensen & Christensen (1982) could not demonstrate differences in marginal integrity, color match or marginal discoloration between a microfilled and a conventional composite resin after 3 years. Only a few studies with a duration up to 2 years have compared microfilled or hybrid composites with conventional composites (Heuer et al 1982, Kullmann 1985). No study has compared the three resin types over longer periods of time.

Mjör (1981) reported in a study based on questionnaires, that poor anatomical form was the major reason (41%) for replacing composite resins in private practice, followed by recurrent caries (20%) and intrinsic discoloration (13%). More than half the restorations were replaced within 7 years. In a later study of the same type, Mjör (1985) reported that recurrent caries was by far the most frequent reason for replacing composite resins (43%). Crabb (1981) reported that 39% of the investigated anterior composite fillings and 68% of the silicate fillings were replaced after 5 years. No distinction between the different composite resin types was made in these studies.

The interest in posterior composite resins has grown rapidly initiated by a demand for esthetic dentistry and by a concern over mercury toxicity. Several aspects of the properties of the resins have been studied clinically but the main interest has been focused on resistance to wear. Inadequate resistance to wear was the major reason for the relative short life spans of conventional composites (Phillips et al 1973, Eames et al 1974, Leinfelder et al 1975). Later, resistance to wear was improved by using materials with increased amounts of smaller and softer filler particles (Vrijhoef et al 1985, Lambrechts 1983, van Groeningen 1984, Wilder et al 1984, Dogon et al 1985, Hendriks 1985, Lambrechts et al 1985, Lutz et al 1985, Boksman et al 1986, Leinfelder et al 1986, Council on Dental Materials 1986).

Marginal adaptation becomes a major problem for the posterior fillings. Because of larger movements during polymerization it is
particularly necessary to improve the marginal adaptation along the gingivo-proximal margin. Attempts have been made by using an incremental placement technique (Jörgensen and Hisamitsu 1984), indirect curing with light reflecting wedges (Lutz et al 1986) and the use of glass ionomer cement as a build-up base material reducing the size of the composite restoration (Mc Lean et al 1985). The results from these studies cannot yet be evaluated.

Many clinical evaluations of posterior composite fillings do not show that recurrent caries is a problem. Most studies, however, have been done on university faculty members, dental students or dental hygienists none of whom are representative populations with respect to caries activity.

Potential caries risk

Caries development around a filling is a function partly of the properties of the material and the handling technique used and partly of the individual's susceptibility to caries. It is therefore obvious that the role of the filling in caries development can only be evaluated if the role of the patient is known. An evaluation of the potential caries risk for the individual member of the study must be made. On a group basis, determination of the number of lactobacilli and *Streptococcus mutans* in saliva or dental plaque, has shown a positive correlation between the number of microorganisms and the caries activity (Klock & Krasse 1978, Crossner 1981, Zickert et al 1983). When one variable at a time - e.g. buffer capacity, sugar intake, amount of lactobacilli or *S. mutans* in saliva and oral hygiene - is tested for its relationship to dental caries, no or only weak correlations with caries activity were found (Bagramian et al 1974, Grahnén et al 1977, Ainamo 1980, Bellini et al 1981, Eriksen et al 1986). When a concerted evaluation of several caries related variables is made the possibility of evaluating the potential caries risk for an individual is increased (Rundegren & Ericson 1978, van Dijken et al 1986, Bergman & Ericson 1986, VII, Stecksén-Blicks 1986). The multifactorial nature of the caries disease inevitably disqualifies the use of any single test as the sole basis for an
evaluation of the caries risk of an individual. The prediction of caries is improved when several test parameters are combined.

Summary

Despite the improved qualities of the composites over the unfilled resins, the conventional composites still revealed a number of disadvantages which led to clinical problems. Polishing difficulties and problems in obtaining lasting smooth surfaces led to rough filling surfaces with large amounts of plaque formed, and to gingivitis. Discoloration led to the need for rapid revisions of the fillings. Porosities within the resin material led to increased wear, water absorption and surface roughness. A relatively high polymerization shrinkage led to gap formation in the unetched parts of the fillings and to internal stress in the composite resin, enamel or material/enamel interface of the acid-etched cavity margins. There is some controversy about the reported frequency of recurrent caries around composite resin fillings. No consideration was taken in these studies to the potential caries risk of the individuals. No studies have been published comparing the conventional composite resins with the new microfilled- and hybrid composites regarding the surface characteristics and irritating effect on the gingival margin. No study has compared the marginal adaptation and clinical behaviour of the three types of composites either longitudinally or intra-individually.
AIMS

The aims of the present investigations were to examine

- the effect of commonly used finishing techniques on the surface texture of different composite resins.

- porosities in different composite resins.

- the effect of different types of composite resins on the marginal gingiva.

- the effect of the use of an intermediate low-viscous resin on the marginal adaptation of microfilled and hybrid composite resin fillings.

- the clinical quality and durability of different types of composite resins in anterior cavities.
METHODS

Preparation of test specimens. In Study I, the specimens were prepared by allowing the resin to set in plastic molds for six minutes under pressure. The specimens were then kept in moist chambers before further handling was carried out.

In Study II, test specimens were prepared in two ways: using a pressure method and a condensation method. The pressure method was essentially the same as in Study I, but a higher pressure was exerted by means of a clamp. The clamp was left in place during polymerization of the chemically activated materials, while it was removed for the light-activated materials which were then activated in five different spots. This method is recommended in the ISO standard ISO/4049 (1985) for preparing specimens in order to evaluate water absorption and solubility. The condensed specimens were prepared in small quartz glass tubes. The chemically activated resins were placed in the tubes with a spatula and the light-activated resins with the delivery syringe. The materials were then condensed in the tubes with a circular (diameter 2 mm) smoothfaced amalgam condensor, using light pressure. The tubes were filled and cured stepwise. The 6 mm high specimens were cut transversely in the middle. Five test specimens with a height of 2.5 mm and a diameter of 4 mm thus obtained for each product were used.

Scanning electron microscopy (SEM) was made of polished specimens mounted on metal stubs and then coated with a layer of gold. The surface roughness and porosity evaluations were based on the photomicrographs taken. Surface roughness was evaluated qualitatively on a descriptive base (I), while porosity evaluations were measured quantitatively as pore size and pore area using a semi-automated computer based picture analysis method (II).

SEM replica was used in two in vivo studies, to study the surface characteristics (III) and marginal adaptation (III, VI) of different composite fillings. Replica samples for SEM were prepared by first cleaning the filling surfaces with a surface active cavity cleanser (III) or a 5 % sodium hypochlorite (NaOCl) solution (VI), followed by
spraying with water and drying with compressed air. Impressions of the cleaned surface were made with a low viscous silicone impression material. The replica was prepared by filling the impression with Epon (TEM bedding-in resin, Fluka AG, Buchs, Switzerland). The positive casting was mounted on metal stubs, covered with gold and then studied in the SEM. The final evaluations were based on photomicrographs. The surface characteristics were evaluated on a descriptive base using photomicrograph standards (III). The marginal adaptation was evaluated descriptively (III, VI) and quantitatively (VI).

Selection of patients for the in vivo studies (III-VII). The patients had to fulfill certain criteria in terms of number and localization of fillings required and non-filled enamel surfaces present in the anterior region. The number of fillings required in each patient was determined by the need to make intraindividual comparisons of the different composite resin fillings or placement techniques. Each patient received at least one filling of each of the investigated materials/placement techniques. In this way each patient served as a statistical unit. The patients included in the longitudinal evaluation of the different types of composite resins (VII) had up to twelve caries lesions at the start of the study.

Filling margins located subgingivally were required in Studies IV and V, while the fillings in the individual patients in Studies III, VI and VII were located either at the gingival margin or subgingivally in order to obtain similar conditions for the different materials/techniques in each patient.

Restorative procedure. The cavity margins in the enamel were bevelled, whereas the unsupported enamel, mostly at the gingival margins, was removed with finishing burs at low speed (III-VII). The operative field was then subjected to moisture control with cotton rolls and saliva suction equipment (III, VII) or with rubberdam (IV-VI). The cavities were then dried by an air blast and cleaned with a surface active cavity cleanser. When a dry operation field could not be obtained at subgingival margins these were exposed electrosurgically (III, VII). A layer of calcium hydroxide base was applied before acid etching of the bevelled enamel cavity margins. The bevelled margins were etched for 60 s with 37 % phosphoric acid. After thorough spraying with water (20 s) and drying with compressed air, either a
low-viscous intermediate resin followed by a composite resin (IV-VI) or the composite resin alone (III, VI, VII) were inserted. Excess low-viscous resin was removed by a gentle blast of compressed air immediately after placement. During polymerization the composite resin was kept under pressure with a matrix. The fillings were finished after one week.

Clinical recordings. Plaque index (Silness and Löe 1964), gingival index (Löe and Silness 1963), bleeding on probing (Ainamo and Bay 1976) and flow of crevicular fluid were measured in a cross-sectional (IV) and one experimental gingivitis study (V). The flow of crevicular fluid was recorded with standardized filter paper strips (Löe and Holm-Pedersen 1965) placed at the orifice of the gingival pockets for three minutes. The strips were then stained with an alcoholic solution of 2% ninhydrin (Orban and Stallard 1969). The coloured area of each strip was measured under a microscope with an ocular grid (Egelberg and Attström 1973).

A slight modification of the USPHS-criteria (Ryge and Cvar 1971) was used to describe the clinical behaviour of brands of conventional, microfilled and hybrid composites (VII). Using this rating system the restorations were evaluated visually and with mirror and probe as regards extrinsic discoloration, color match, marginal discoloration, marginal adaptation, surface roughness and the presence and location of recurrent caries. The rating system is based on the basic clinical qualities of a restoration: acceptable or not acceptable. These qualities are further divided into subratings. The evaluations were made every six months over a six year period after polishing of the fillings.

Caries risk evaluation. A prediction of the caries risk, expressed as the potential caries activity, was made for the patients involved in a longitudinal evaluation of different types of composite fillings (VII). The prediction was compared to the actual caries development in each patient. The potential caries activity was defined by the caries risk estimated from the net effect of microbial counts, oral hygiene, intake of fermentable carbohydrates, salivary flow rate and buffer pH. The recorded parameters were regarded as negative factors favoring caries development when certain values were exceeded (Rundegren and
Ericson 1978, van Dijken et al 1986). The parameters were recorded three times during the six year evaluation period. Oral hygiene was defined as a negative factor when a plaque score of more than 2 or gingival bleeding at more than 30 % of the tooth surfaces were recorded on more than one occasion. Samples of stimulated whole saliva were collected into ice-chilled tubes by chewing on a lump of paraffin. The numbers of colony forming units (CFU) per ml saliva of lactobacilli (Carlsson et al 1975), total streptococci and S. mutans (Jordan et al 1968) were determined as well as buffer pH (Ericsson 1959) and flow rate. The presence of more than $5 \times 10^5$ CFU/ml saliva of S. mutans and $10^5$ CFU/ml saliva of lactobacilli on two of three occasions, were regarded as negative factors as was a buffer pH of 5.3 or lower (Ericson 1972) and a flow rate of 0.75 ml/min or less. A mean intake of fermentable carbohydrates six times a day or more was regarded as a negative factor. The dietary record was based on a four day protocol (Carlgren and Rossander 1982). For each individual a maximum of six negative factors could thus be obtained.

Statistical analysis. The surface characteristics of the composite materials were presented on a descriptive base (I, III). In the in vivo studies, when different types of composite fillings and/or filling techniques were compared, each patient received at least one of each of the types of fillings investigated and served in this way as a statistical unit. To eliminate the effect of an uneven representation of materials in each patient (VII), the number of fillings from each material with a given index score were normalized to the total number of fillings with that material in the particular patient. For example, out of four fillings made from one material placed in a patient, one (25 % of these fillings) may have a score of 0 for a particular factor, one (25 %) may have score 1, and two (50 %) may have score 3. When the relative frequencies in each patient are known the scores for a factor can be calculated for all patients. For observations on an ordinal scale - e.g. plaque index, gingival index, the classification in the USPHS-system (IV-VII) - the relative frequencies (%) of the scores for each material within each patient were compared, ranked and tested using Freedman's two-way analysis of variance test (Siegel 1956). When the null hypothesis was rejected or when all brands were not represented in each patient (VII), the materials or techniques were compared two at a time using the sign test (Siegel 1956).
The size of the marginal defects (VI) between independent samples in the various test groups, were tested using the Mann Whitney U-test (Siegel 1956), while the related samples - the one-week and one-year samples in each of the test groups - were tested using the Wilcoxon matched-pairs signed rank test (Siegel 1956).

The differences between two materials or between one filling and the enamel surface regarding the amount of crevicular fluid secreted were tested using the Students t-test for paired observations (IV, V). The increase in the amount of exudate between day zero and day seven in Study V, was compared using a two-way analysis of variance (Steel and Torrie 1960).
RESULTS


The effects of twelve finishing procedures on the surface textures of two anterior conventional composites, two anterior microfilled resins and a glass ionomer cement were investigated. The final evaluations based on the SEM photomicrographs, showed that the microfilled composite resins are superior in finishability to the resins loaded with larger filler particles. The use of fine grit devices resulted in smooth surfaces. In contrast the macrofilled composites showed rough surfaces with protruding filler particles. Only the Sof-lex polishing system produced smooth surfaces on all composite resins, whereas the use of a polishing paste led to very rough surfaces on the macrofilled resins.

CONCLUSION: Microfilled materials are superior to macrofilled materials as regards the possibility of obtaining and retaining a smooth surface.


The pore area (%) and the pore sizes were measured in 90 specimens made of eight brands of posterior composites and one anterior composite. Six materials were light-cured and three chemically cured. The specimens were prepared in two ways: condensed specimens, in order to simulate the clinical situation and pressure specimens according to the ISO standards for laboratory test specimens. Porosities occupied 0.01-4.5% of the surface depending on the material. Most of the materials, including all those chemically activated, showed more porosity in the condensed than in the pressure specimens. Reversed results emerged for two of the materials, and for another two, the specimens were similar in this respect. The mean pore sizes were smaller in the condensed than in the pressure specimens.

CONCLUSION: Neither mean pore size nor total amount of porosities could be related to the curing method of the composite resins.


A SEM replica technique was used to study the surface roughness and marginal adaptation of 278 anterior resin fillings. The fillings were made of two conventional, three microfilled and two hybrid composite materials. After 3-4 years in vivo, replicas were made. The surface roughness studied by SEM was graded by using photomicrograph standards. The degradation of the bonding between the acid etched enamel and the filling material was investigated in two specified areas, one located on the incisal part and one on the gingival part of the etched margin of each filling. The 3/4-year-old composite restorations showed degradation of surfaces and margins, with eroded areas and exposed filler particles. Cohesive failures were seen as chip fractures and marginal fractures parallel to
cavity margins. Rough surface characteristics increased in the following order: 1) light-cured microfilled, 2) chemically cured microfilled, 3) hybrid and conventional composites. A light cured microfilled resin showed the smoothest surface characteristics with less surface degradation and porosity. Marginal defects were seen in about 50% of the conventional and hybrid composite fillings. Defects occurred in 66-88% of the chemically cured microfilled resins but in only 44% of the visible light-cured microfilled resin. Marginal defects were observed more frequently in stress bearing fillings than in non-stress bearing ones. **CONCLUSION:** The type of filler particle seems to determine the final surface characteristics.


The effect of conventional, microfilled and hybrid composite resin fillings on the gingival health was evaluated in two groups of patients. The plaque and gingival indices were recorded in both groups. In addition, the flow of crevicular fluid was recorded in the first study and bleeding on probing in the second group. Group one consisted of 18 adults. A total of 108 fillings were made. Two conventional fillings were inserted in neighbouring surfaces in one proximal space, two hybrid composite fillings in a second proximal space and two microfilled resin fillings in a third proximal space in each patient. One proximal space in the region contained two non-filled enamel control surfaces. The observations were made one year after insertion of the fillings.

Group two consisted of 24 adults with 228 subgingival, anterior Class III and IV composite fillings which were 3-4 years old at the time of registration (c.f. III). Each patient had at least one filling of each of the three composite types and at least one non-filled enamel surface to allow for an intraindividual comparison. The patients were not informed about the registrations in advance of the visit.

In group one the figures for the amount of plaque on and degree of gingivitis around the composite fillings were not significantly higher than the figures for the enamel surfaces. Significant differences in the amount of crevicular fluid were found between both the conventional and the hybrid composites and the enamel. In group two the indices for each resin type were significantly higher than those for the enamel surfaces and the fillings showed greater amounts of plaque and a higher degree of gingivitis than the 1-year old fillings. **CONCLUSION:** The degree of gingivitis increased with time. As concerns the amount of plaque formed and the occurrence of gingivitis, there was no difference amongst the 3 types of composite resins.


The development of experimental gingivitis around one-year-old restorations made from the three types of composite resins and around enamel surfaces was studied. 18 patients (IV) started an oral hygiene regime aimed at eliminating all marginal gingival inflammation in the experimental area. When the gingival index scores approached zero, the experimental period of seven days started. The early signs of gingivitis were significantly fewer around the intact enamel surfaces than around the composite surfaces. Neither the clinical indices nor the exudate measurements showed any differences in this respect between the three composite resin types.
CONCLUSION: All types of composites promote gingivitis to the same extent.


The marginal adaptation to acid-etched enamel of hybrid and microfilled resin fillings, placed with or without intermediate low-viscous resin was investigated in vivo. Class III fillings were placed in either the upper or lower front teeth in 37 adults. Each patient received two hybrid and two microfilled composite resin fillings. One of each composite resin filling was placed using a low-viscous resin recommended by the manufacturer of the composite material.

After one week no difference was seen between fillings of the same material placed with or without intermediate resin. After one year the hybrid resin fillings placed using intermediate resin showed better adaptation than the ones without, while no differences were seen between the microfilled resins. The microfilled resins showed a greater number and more severe defects than the hybrid resins.

CONCLUSION: Hybrid resins placed using bonding agent had the best marginal adaptation.


The clinical behaviour and durability of 303 anterior resin fillings of seven composite materials - 2 conventional, 3 microfilled and 2 hybrid - were evaluated over a six year period. The restorations were placed in 27 patients including patients who experienced relatively high levels of caries. Each patient received at least one filling of each of the three composite resin types. Each restoration was evaluated with respect to extrinsic discoloration, color match, marginal discoloration, marginal adaptation, surface roughness and the presence and location of recurrent caries. A prediction of potential caries activity was made for all patients. The prediction, based on six caries risk factors, was compared to the actual caries development during the six year period in each patient. Unacceptable color match scores varied widely among the brands (3.5-79.7%) after six years. Unacceptable marginal discoloration was seen in 1.7% of the restorations, while unacceptable marginal adaptation varied among the resins (13.7-37.3%). Recurrent caries occurring at the margins of the composite fillings varied among the materials (9.3%-29.4%). During the experimental period between 14.8% and 55.1% of the fillings of each material were replaced per patient. Recurrent caries was the major reason for replacement.

CONCLUSION: There was a wide variation in clinical behaviour and durability within each composite resin group. Recurrent caries was the major reason for replacement. Patients with a high number of caries risk factors showed a clearly higher increment of caries, especially of recurrent caries around composite fillings.
GENERAL DISCUSSION

The evaluation of a filling material can be made in vivo or in vitro. In vivo investigations are generally based on an evaluation made by the probe and visual inspection (Smales and Creaven 1979). The information obtained in this way about roughness, marginal adaptation and color matching has the weakness of not being quantitized. The systematic evaluation suggested in the USHPS-system (Cvar and Ryge 1971) helps to standardize the evaluations but as the system is based on only a few scores it is not sufficiently sensitive for testing a small number of samples in an experimental series. It is more suited for use on larger populations in epidemiological evaluations. Attempts to increase the number of descriptive ratings have merely resulted in poorer evaluator agreements (Mjör & Haugen 1976).

It is now general consented that clinical investigations should be performed as a final evaluation of new restorative materials, but the majority of the composites introduced to date on to the market have not been subjected to previous clinical investigations. Dentists are often obliged to base their judgements on the information applied by the manufacturers. Several problems arise in long-term clinical studies of composites; the uneven composition between batches of the same product, the change of composition, and the disappearance of materials from the market before substantial clinical tests have been performed (Lambrechts 1983, VII).

It is difficult to predict clinical behaviour from laboratory tests, which determine only whether a material has the potential for clinical use. The shortcomings of the subjective clinical assessment methods have led to the development of more objective ranking methods. By making replica models of the surfaces (III, VI) direct measurements can be made of defects in the surface. This provides more objective evaluations of the quality of the surface. Another possibility is to make a multipower enlargement of the replica sample or of a cross-section of it (van Dijken and Hörstedt 1986, 1987a) to make possible a visual inspection of defects. Such defects although of a magnitude that might indicate biological risk would not be recognized by a probe. SEM observations offer an excellent means for evaluating surface roughness qualitatively (I, III, VI) and the enlarged
structures can be used for morphometric measurements (II). By using replicating techniques it is also possible to monitor continuing in vivo changes in surface morphology for extended periods of time.

The finishing of conventional composite resins still raises serious problems. The difference in hardness of the two major parts of the materials is such that a smooth finish cannot be obtained with the traditional polishing procedures (I). Some microfilled materials were introduced in the seventies and the manufacturers claimed that they could be polished to a smooth surface. At the same time new polishing devices were designed to produce smooth surfaces on the various composites. In vitro studies of the effect of polishing procedures on various anterior and posterior composites with the SEM and profilometer (I, van Dijken et al 1983, van Dijken and Ruyter 1987), confirmed that microfilled composites could be polished to a smooth surface. The macrofilled conventional and hybrid composites showed two different abrasion patterns (van Dijken and Ruyter 1987). One was seen after the polishing disc system was used. The filler particles and resin matrix were flattened equally, resulting in low Ra values and seen in the SEM as having the characteristics of a relatively smooth surface. The other abrasion pattern was seen after brushing with polishing pastes resulting in the preferential removal of the organic polymer matrix leading in turn to a protrusion of the filler particles. Toothbrushing in vitro of the smooth surfaces of various macrofilled composite resins obtained initially by Sof-lex (3M Dental Products, St Paul, MN. USA) polish also showed a marked increase in surface roughness. The SEM evaluation showed the disappearance of the smooth smear layer obtained with the Sof-lex polish (van Dijken et al 1983, van Dijken and Ruyter 1987). The differences in surface structure between the various macrofilled composites clearly demonstrated the influence of the size, hardness and amount of the filler particles on the abrasion pattern. The traditional quartz particles show very little wear compared to the glass particles in the newer hybrid composites (van Dijken and Ruyter 1987). The development of composite resins with a high content of smaller and softer glass particles produced materials with surface profiles which after toothbrushing resembled very closely those of the microfilled composites.
The toothbrushing abrasion patterns observed in vitro (van Dijken et al 1983, van Dijken and Ruyter 1987) were also seen in vivo (III, VI). Aged composite fillings loaded with large filler particles studied with a SEM replica technique showed rough characteristics in vivo similar to those found on in vitro samples (III). In comparison to newly finished surfaces the aged microfilled resins showed an increased roughness, in the form of eroded surface areas, crack formation and chip fractures. It should be observed that in aged microfilled resins patches of roughness occurred which gave them an overall smoother character than the aged macrofilled composites, which showed rough characteristics over the whole surface.

It can be concluded that the final surface structure of a composite filling will be determined by toothbrushing procedures in vivo. The use of polishing procedures resulting in smooth but easily abraded superficial layers or polishing devices with more finely grained and softer abrasives than those found in commercial dentifrices have no lasting effect. The clinical degradation of the composite surfaces occurred not only because of the mechanical forces and abrasion of the toothpaste but also as a result of a combination of thermomechanical fatigue and chemical attack.

Differences in surface roughness between materials with a similar filler content can be influenced by the number and size of pores in the surface of the composite. Pores, which are caused by entrapped air are common in dental composites and are closely correlated to mixing and handling procedures. Light-activated resins have been shown to exhibit in vitro both fewer and proportionally smaller voids than chemically activated resins (Reinhardt et al 1982). This was also seen in an in vivo study (III) where a light-cured microfilled resin showed considerably fewer pores than two chemically cured ones. However, in an in vitro study of porosity in posterior composite resins, two of five light-cured resins showed roughly the same number of pores as the chemically cured composites. This means that even if it is possible that light-cured resins exhibit less porosity than chemically cured resins, this cannot be treated as a generalization and should be investigated for each individual material. However, the introduction of light-cured composites properly manufactured and the use of a syringe instead of a bulk packing technique may give composite fillings with minimal porosity.
It has been stated that rough filling surfaces favour the accumulation and retention of debris and bacterial plaque and promote gingivitis (Larato 1972, Mörmann et al 1974, Gildenhuys et al 1975, Smales 1981). Skjörland (1973, 1976) and Sönju and Skjörland (1976) showed, in vitro and in vivo, that the amount of plaque accumulation differed in quantity on the various hard surfaces of the mouth. A comparatively large amount was formed on conventional composites, but its presence was scarcely demonstrable on silicate, amalgam or enamel.

Many restorations are placed adjacent to or below the gingival margin. The surfaces of these restorations have been implicated as possible factors contributing to gingival disease. Waerhaug (1956) noted inflammatory changes around different types of restorative materials and suggested that they were mainly caused by plaque accumulated on the rough area. Löe (1968) reported that the roughness of restorations, probably more than chemical irritation from the material itself, produced inflammation. He concluded that restorations should be well polished to reduce plaque accumulation.

Because of their surface smoothness, the microfilled resins were expected to affect the health of the gingiva less adversely than the rough conventional composites. This argument was also used by the manufacturers when the first hybrid composites were introduced. No study has, however, compared the properties of the three composite resins with respect to plaque accumulation and gingival reaction.

Enamel is probably the smoothest and most acceptable surface in the mouth and all restored surfaces should be compared to it. There are a variety of indices available to assess gingival inflammation. These include those based on changes in gingival color and shape, bleeding tendency, quantity of sulcular fluid and histological data. The histological index probably provides the most accurate assessment of gingival inflammation (Appelgren et al 1979), but beside other objectives the time and level of expertise required to obtain, prepare and score the biopsies limit the application of this method. Alternative gingival indices have therefore been developed for clinical use. Among the most commonly used are the gingival index (Löe & Silness 1963) and the gingival bleeding index (Ainamo & Bay 1975), both of which assess the tendency of the gingiva to bleed on light probing. The bleeding indices are based on the fact that the degree of gingivitis is reflected by vascular changes in the
gingiva. The early inflammatory changes of the gingival index are detected by the subjective observation of surface changes in color and texture. This subjectivity is overcome in the bleeding index, which involves simply scoring bleeding or no bleeding and requires little calibration. To overcome differences in the amount of force applied to the probe pressure-sensitive (force-controlled) probes have been developed.

Another method for evaluating gingival inflammation is measurement of the gingival crevicular fluid (Brill and Krasse 1958), a method based on the fact that when the degree of gingival inflammation increases, the amount of exudate in the gingival sulcus increases. Poulsen et al (1979) showed that measuring crevicular fluid is an efficient method of studying the development of gingivitis in clinical trials, and Cimasoni (1983) stated that it is the most reliable and sensitive procedure available for quantifying gingival inflammation. The gingival index and the gingival exudate fluid may reflect different stages of inflammation in different parts of the gingiva and the pocket region. Improved plaque control may reduce superficial inflammation but may not reduce inflammation at the base of the pocket. Multiple measurements may be necessary to record adequately the severity of the disease and to follow the effect of the patients oral hygiene procedures.

As the rate of plaque accumulation and the development of gingivitis as well as the level of oral hygiene differs more inter-individually than intra-individually, a comparison of different materials with respect to plaque removal, plaque accumulation and appearance of gingivitis can be made only if the various materials are compared in the same mouth. In two cross-sectional studies (IV), plaque was registered on fillings of the three composite resin types with the plaque index (Silness & Löe 1964). It was shown that patients with relatively good oral hygiene were able to clean plaque from the observed supragingival parts of the composite fillings regardless of the type of composite. There were more filled surfaces than there were control enamel surfaces with observable plaque on them. The amount of subgingival plaque is not registered with the Silness and Löe index. To be able to evaluate the condition of the pocket the more sensitive method of gingival fluid registration was used to observe the effect of the subgingivally located fillings on gingival health (IV, V). No differences were seen in crevicular fluid exudation around the
fillings made from conventional, microfilled or hybrid composites, but the amount of fluid around the filled surfaces was always higher than around the unfilled enamel surfaces. The stronger reaction around the composite surfaces may be due to the toxicity of the materials and/or irritation from remains of bacterial plaque.

Differences in plaque retention and properties evoking gingivitis among the different composites were also studied in an experimental gingivitis model according to Löe et al (1965) (V). All composites produced a strong gingival response and the materials were comparable despite the great differences in their surface characteristics.

The results of the two cross-sectional (IV) and the experimental gingivitis study (V) support the observations of Waerhaug (1956), who found that differences in surface characteristics per se had only minimal effects on gingival responses. However, it must be observed that the observations are based on different composite resins in anterior fillings. The differences in plaque accumulation may be even more pronounced when the resins are used in posterior proximal cavities. These areas are more difficult for the patients to clean, while at the same time the plaque accumulation ratio in the posterior region of the mouth is faster than in the anterior part (Lang et al 1973). Differences in gingival responses for the composite resins in posterior fillings should be studied.

The SEM investigation of the adaptation to acid-etched enamel of composite resins placed with or without the use of low-viscous bonding agents (VI), showed defects such as marginal fractures, chip fractures of the resin and fractures in the enamel. It should be pointed out that with the SEM method used, adaptation could be evaluated only at the surface of the fillings. The deeper parts can only be investigated in cross sections of teeth extracted e.g. for orthodontic reasons (van Dijken and Hörstedt 1986, 1987a). The most common defects observed were fractures in the resin material often close to the filling/enamel border. One week after polymerization there was no difference in marginal defects between fillings of the same material placed with or without a bonding agent. The hybrid resins both with and without a bonding agent showed a significantly better marginal adaptation than the microfilled resins (III, VI, van Dijken and Hörstedt 1987b). The contraction stresses during polymerization, which are larger for the microfilled than for the resins loaded with larger filler particles
are likely to be the main cause of fractures in the resin. The severity of the defects for both composite materials increased at the one year registration which indicates a decreased resistance to thermo-mechanical stress in the mouth.

The marginal defects of composite fillings will become clinically important when their severity is sufficient to cause loss of retention, microleakage or increased plaque retention and predispose the fillings to recurrent caries. Retention of composite resin fillings is not improved by the use of intermediate resin (VI, Low and Majid 1979, Ulvestad 1978, Smith et al 1985). In a longitudinal evaluation of fillings of conventional, microfilled and hybrid composites, placed without a bonding agent (VII), no caries occurred at the etched margins. The margins most prone to caries were the cervical margins, when the acid-etch technique could not be used. Bacterial penetration will occur easily along those margins and in combination with long clearance times for bacterial acids a higher frequency of caries could occur. It can be concluded that the failures observed in the acid-etched margins do not necessarily lead to clinical complications in the studied anterior composite fillings, even if a low viscous resin was not used. In larger fillings it may be assumed that bonding agents are more necessary. During longer application times the viscosity of the composite resin increases, and the resin will not penetrate the etched enamel as easily as the freshly mixed material (Jacobsen et al 1977). Further investigations are most essential so that ways of improving the cervical marginal adaptation of composite resin fillings can be discovered possibly by finding resins with low polymerization shrinkage.

The clinical implications of recurrent caries is both a restoration quality problem and a caries problem. Eriksen et al (1986) reported that an increase in the prevalence of recurrent caries around amalgam fillings could be registered only for the fillings reaching a marginal breakdown pattern resulting in quality scores of 5 and 6 on an 1-6 ranking scale. Goldberg et al (1981) showed that for the smooth surfaces a correlation existed between recurrent caries and moderate/severe marginal quality. No such relationship was found for the occlusal surfaces. Eriksen indicated that recurrent caries is not primarily a restoration problem, but is intimately related to the
caries—challenge of the patients. Unfortunately no such studies have been performed previously for composite resin fillings.

In a recent study Mjör (1985) reported that recurrent caries was by far the most common reason (41%) for replacement of composites in private practice. In other studies the fillings had lasted up to 4 and 5 years with a very low rate of caries or no recurrent caries (Chandler et al 1973, Leinfelder et al 1980, Qvist et al 1980, Ström and Qvist 1986).

The higher prevalence of recurrent caries around composite fillings compared to amalgam and gold restorations as shown by Eriksen et al (1986), was also shown in Study VII. In this study 18.6% of the composite restorations exhibited caries at the end of the six years. Variations in caries susceptibility among individuals must be considered before any comparisons between materials can be made as regards evaluation of the frequency of recurrent caries. Use of dental students or other groups with a low caries risk results in an underestimation of the chances of recurrent caries (Leidal & Dahl 1980), a circumstance that underlines the importance of the selection of patients in clinical studies. In this thesis we have used an evaluation system for caries risk first suggested by Rundegren and Ericson (1978). It is based on the assumption that the possibility of accurately predicting caries risk in a patient increases when several caries related factors are evaluated. In this study the evaluation is based on a calculation of the sum of negative evaluations of 6 factors. We find that patients with a higher number of negative factors develop more caries. The system of Rundegren and Ericson was also used in studies by Bergman and Ericson (1986) and van Dijken et al (1986).

In Study VII we found that patients with a high potential caries risk clearly showed a greater actual development of caries, especially of recurrent caries, contiguous to the composite fillings. The fact that 46% of the recurrent caries lesions on the buccal surfaces were registered as root surface caries, can be seen as a contra-indication for composite resins as the material of choice in these cavities. The choice of tooth-colored material in the individual patient should depend very much on the patients caries susceptibility. In older patients with three or more negative factors one must reconsider the use of composites, especially in teeth with gingival recessions.
Materials which leak fluor like the glass ionomer cements should be used (van Dijken 1986).

Body discoloration as a reason for the replacement of anterior fillings was reported to reach 13% of the total number of replaced fillings in a cross-sectional study of fillings made in private practice (Mjör 1981). Ulvestad (1978) reported that 83% of five year old conventional chemically cured fillings were cosmetically poor. Dogon et al (1985) replaced 43.7% fillings made of a chemically cured microfilled resin and only 1.5% of the light-cured variation after 3 years of use. On the other hand, Ström and Qvist (1986) reported that only 2% of fillings of the same chemically cured resin showed unsatisfactory color match after a four-year assessment.

A yellowish/brownish mismatch due to body discoloration has been reported with increasing age in several longitudinal investigations (Eriksen 1974, Ulvestad 1978, Qvist et al 1980, Leinfelder et al 1980). The color shift in connection with aging of chemically cured resins has been ascribed to the oxidation of residuals of certain tertiary amines present in the catalytic system and to the amount of inhibitor (Asmussen 1983). Discoloration by oxidation of the unreacted methacrylate groups has also been considered to be important (Ruyter & Svendsson 1978). Light-cured materials were more color stable since they are polymerized by a mechanism in which aromatic amines are not required (Asmussen 1983). However, the color stability will depend on the particular brand or batch, because some products contain amines or inhibitors that may break down and liberate colored agents.

The number of fillings replaced because of discoloration in Study VII do not necessarily represent the number of fillings with a non-acceptable color match. Patients tended to have a more lenient attitude and sometimes accepted a discoloration which the dentist wanted to color adjust (Ulvestad 1978, VII). From Study VII it is clear that the color change is time dependant and varies greatly among the materials. The results clearly show that periods longer than three years are required to evaluate the clinical color stability of composites.
GENERAL SUMMARY AND CONCLUSIONS

Microfilled composite resins were superior to composites loaded with larger filler with regard to the possibility of obtaining and retaining a smooth surface. Porosities in the resins was one of the factors which determined surface roughness. The number of porosities varied greatly among the investigated composites and could not be related to the curing method employed. The surface characteristics of composite resins aged in vivo showed degradation of surfaces and margins. The chemically cured microfilled resins showed more marginal defects than a visible light-cured microfilled resin and the conventional and hybrid resins.

The difference in surface characteristics and composition of the conventional, microfilled and hybrid composites did not result in clinically measurable differences in the amount of plaque and degree of gingivitis around the resin types measured either during a period of normal oral home care in the investigated patients or during the development of plaque and gingivitis in an experimental gingivitis study.

The use of a low-viscous intermediate resin produced no effect on the marginal adaptation of microfilled resins to the etched enamel. The hybrid resin fillings placed with a bonding agent showed better adaptation than the ones without after one year.

Despite their smoother surface characteristics, the microfilled resins showed no advantage over the conventional and hybrid resins regarding their effect on the gingival health, marginal adaptation or frequency of recurrent caries. Since the materials are classified in accordance with the content and size of the filler it may be suggested - based on the large variations within the resin groups - that the filler component per se is not the determining factor for the durability of the composite filling. In Table I a comparison is made of rankings for different composites with respect to some of the selected variables in Papers III and VII.
Table I. Ranking of the criteria evaluated in studies III and VII. The material judged "best" for each individual criterion was ranked lowest

<table>
<thead>
<tr>
<th>Code</th>
<th>surface roughness</th>
<th>marginal defects</th>
<th>marginal degradation</th>
<th>recurrent caries</th>
<th>loss of retention</th>
<th>color match</th>
<th>I ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>VII</td>
<td>III</td>
<td>VII</td>
<td>VII</td>
<td>VII</td>
<td>VII</td>
<td>VII</td>
<td>III-VII</td>
</tr>
<tr>
<td>Conv.</td>
<td>A</td>
<td>7</td>
<td>2.5</td>
<td>2.5</td>
<td>1.5</td>
<td>3</td>
<td>18.5</td>
</tr>
<tr>
<td></td>
<td>P</td>
<td>4</td>
<td>2.5</td>
<td>5</td>
<td>1.5</td>
<td>4</td>
<td>21</td>
</tr>
<tr>
<td>Microf.</td>
<td>S</td>
<td>2</td>
<td>4</td>
<td>6</td>
<td>6</td>
<td>5</td>
<td>28</td>
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<td></td>
<td>Du</td>
<td>1</td>
<td>2.5</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>11.5</td>
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<tr>
<td>Hybrid</td>
<td>M</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>6</td>
<td>6</td>
<td>7</td>
<td>4</td>
<td>7</td>
<td>35</td>
</tr>
</tbody>
</table>

It is quite clear that there are wide variations among materials within each type. It should also be observed that judgements based on testperiods shorter than 3 years long are unreliable. Each new composite resin must be evaluated on its own merits and not because it belongs to a certain group. One of the microfilled resins has a better ranking than any of the other materials tested. However, in spite of this it was not superior in terms of recurrent caries or marginal adaptation. Great respect should be exercised for the delicate techniques involved in making a composite filling. A good technique and a careful evaluation of the caries risk of a patient are essential if there is to be a good result. Because recurrent caries will certainly become the major reason for replacement it is important to include caries risk patients in a clinical evaluation.

The introduction of the newer composite types has not yet completely satisfied the demand for a durable anterior restorative. The composite resins have replaced the silicate cements regardless of the caries susceptibility of the patients. It is suggested that the composites should not be used as the only tooth colored restorative, but that its indication should be based on the patients caries risk level. In patients with a high caries risk level a fluoride-leaking material such as the glass ionomer cements should be preferred.
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