Fig. 3 - Locations for the placement of pins. 3.1 - Locations according to Marzouk, Simonton and Gross (1985, p. 213). ● - ideal locations, △ - areas to be avoided, □ - second choice. 3.2 - Locations suggested for direct composite resin crowns. 3.3 - Locations suggested for direct composite resin crowns in extreme cases, when nearly all of the supragingival tooth structure is missing. + - first alternative, ○ - second alternative. L - labial side, M - mesial side.
2.4.6 Post-cores.

The post-core system is a device used in endodontically treated teeth prior to their treatment with crowns. The core is the supragingival part of the system and it is retained by the post, also called the "dowel", which is placed in the root canal (Shillingburg and Kessler, 1982, p. 14).

It is debatable whether posts were utilised in the ancient world (Zias and Numeroff, 1987), and little progress appears to have been made in the following centuries. In the early 18th century Fauchard used what he called "tenons", screwed into roots to retain bridges (Tylman, 1970, p.4; Hoffmann-Axthelm, 1981, p. 203-204). The less said about the "pivot crowns" of the 19th century, the better - the wood of their wooden "pivots" provided retention by swelling in the mouth (Tylman, 1970, p.4). However, later in that century further progress was made and cements were developed (1.2) allowing cementation of metal posts into the root canals. At around the turn of the 20th century, techniques for casting gold were developed (Hoffmann-Axthelm, 1981, p. 295-7), leading to fabrication of cast gold post-cores. These are still used, but in recent years they have been somewhat displaced by numerous prefabricated systems. It would be beyond the scope of this treatise to detail these systems, or the techniques associated with them, but it is reasonable to say that, because of the various conditions treated, no single system provides the universal answer. The dentist's choice should be guided by what is required of the post-core system in each particular case.

Basically, the post-core system has two functions (Chan and Bryant, 1982; Hunter and Flood, 1989a, 1989b): it strengthens the
tooth which itself provides retention for the crown, or, if there is insufficient tooth structure to provide the retention for the crown, the post-core provides it.

Whether the endodontically treated tooth is actually strengthened by a post-core system is a matter of considerable controversy. Some authors have concluded that it actually weakens the teeth (Greenfeld and Marshall, 1983), others have shown that it may considerably strengthen the tooth (Kantor and Pines, 1977), yet others found it caused no statistically significant difference (Guzy and Nicholls, 1979), and much depends "on an individual assessment of literature" (Hunter and Flood, 1989a).

It would appear, however, that statements such as "all anterior and premolar teeth which are to receive crowns following root canal therapy should have at least one post placed" (ibid.) and "by no means will they reinforce or improve the strengths of these tooth structures" (Marzouk, Simonton and Gross, 1985, p. 216) are too dogmatic. Particularly with direct composite resin crowns, the former statement appears less valid, because very little tooth reduction will occur during the preparation (2.4.3.1). Sound advice, which is a specific application of the general rule (2.4.1.1), was given by Hunter and Flood (1989a): "the advantages of post placement must compensate for the possible decrease in tooth strength which occurs while preparing the tooth to accept it."

In the interests of uniformity, in vitro studies generally deal with intact teeth. In the clinical situation, one may encounter teeth where parts of the crown have been destroyed by caries, accidents or endodontic efforts. Parts of the clinical crown may be sound, but no longer adequately supported. It is important to retain
maximum tooth structure (Henry, 1977). Thus post-core systems, which require as little removal of tooth structure as possible and which support the remaining tooth structure, should be considered.

Where a "greatly enlarged, widely flared canal exists" a cast post-core may be used (Hunter and Flood, 1989a). However, Chan and Bryant (1982) found that crowns supported by steel prefabricated post (1) and composite resin (2) cores failed at higher loads than those supported by cast gold post-cores.

With direct composite resin crowns it is also important that the crown can be bonded to the composite core, providing the organic phases are compatible (2.4.8.6). Chemical bonding to the cast gold core is not possible (2.4.8.8). The use of a cast gold core also negates one of the advantages of the direct composite resin crown—that it may be constructed in one visit.

Sorensen and Martinoff (1984) examined the failures (tooth fractures, root perforations and dislodgement of the post-core systems) in 1273 endodontically treated teeth. They found that the failure rate for teeth without reinforcement was 10.1%. Teeth with cast tapered post and core had a slightly higher failure rate of 12.7%. The best results were achieved by cast parapost and core, with a failure rate of 0% and parapost and composite resin (or amalgam) core with a failure rate of 2.3%. Interestingly, they found that there were no failures when the length of the "dowel" was 1.25 (or more) times greater than the length of the crown. Lewis and Smith (1988), in their study of failed post retained crowns, also found that "many of the failed posts in this study were short".

The length of the post has an influence on the second function of the post-core—retention. The longer post has better retention
(McKerracher, 1981a). Johnson and Sakamura (1978) found that increasing the length of the dowel from 7 or 9 mm to 11 mm increased retention by 24 to 30%. The length of the post is limited by the length of the root, as the apical seal should not be disturbed. Hunter and Flood (1989a) state that the recommended lengths of preserved root canal filling have ranged from 3 to 5 mm, with 4 mm appearing to be the most popular.

Other factors have an influence on the retention, namely the diameter of the post, its shape and its surface configuration. Johnson and Sakamura (1978) found that larger diameter posts were more retentive. However, Standlee, Caputo and Hanson (1978) found that the influence of the diameter was not statistically significant. The increase of the diameter of the post by widening the canal (that is, by removing dentine from the canal walls) is a risky procedure. While McKerracher (1981a) states that from the engineering point of view this is acceptable, there is a widely held opinion that the post should not exceed one third of the thickness of the root. Even if this recommendation may not have been systematically tested (Hunter and Flood, 1989a), the danger of root perforation also increases with the increasing diameter of the post and it needs to be appreciated that not all the dimensions of the root can be determined from a two dimensional radiograph (ibid.).

The shape of the post may be parallel-sided (having the same diameter from one end to another), tapered (of a diameter which decreases in the apical direction) and parallel-tapered (with the occlusal one-half to two thirds parallel-sided and the apical part tapered) (Marzouk, Simonton and Gross, 1985, p.216-217). Of these three shapes, the parallel-sided are "almost 2-3 times more
retentive than tapered ones", while the retention of parallel-tapered posts appears intermediate (ibid., p. 220). According to Johnson and Sakamura (1978), "parallel-sided dowels resist tensile forces 4.5 times more than tapered dowels". However, the tapered dowels they tested were Endodowels (3) with a smooth surface, while the parallel-sided ones were Paraposts (1) with a serrated surface, and the surface has considerable influence on the retention.

The posts may have three main types of surface configuration: smooth, serrated and threaded. Threaded posts are 6-8 times more retentive, and the serrated 3-4 times more retentive, than the smooth ones (Marzouk, Simonton and Gross, 1985, p. 220). Standlee, Caputo and Hanson (1978) found the mean force at which a parallel-sided serrated post (1) failed to be about half of that at which a parallel-sided threaded post (4) failed.

The great retentiveness of threaded posts may provide adequate retention even with shorter posts. Indeed Marzouk, Simonton and Gross (1985, p. 220) state that "for clinical success, 2-3 mm engagement supplies adequate retaining power". However, "it is important to remember that retention is not the sole criterion of a successful post design. In function the restoration has to withstand only limited force in the direction of withdrawal, compared with masticatory, parafunctional and traumatic loads." (McKerracher, 1981a).

Short posts are more likely to cause root fractures, due to unfavourable leverage (DeSort, 1983), although it is debatable, whether the fulcrum is at the height of the "bony attachment" (ibid.) or at the rootface. Threaded posts also can introduce a considerable amount of stress to dentine during insertion (Marzouk,
Simonton and Gross, 1985, p. 218.) During function, a parallel-sided post distributes evenly forces applied parallel to its long axis, but forces applied at an angle (lateral forces) are distributed unevenly, because of the uneven thickness of the dentinal walls of the tapering root around the parallel-sided posts (ibid.). A tapered post will distribute lateral forces evenly, but will concentrate in the apical area the forces applied parallel to its long axis (ibid.) This may create the wedging effect (Greenfeld and Marshall, 1983), but this danger may be alleviated if "the post-core has a positive seat on the root face." (Hunter and Flood, 1989a).

The post-core system has to resist rotational, or torque, forces. With a cast core, this is easily achievable if the root canal is not circular (Baum, Phillips and Lund, 1985, p.543). If the canal is circular, keyways (grooves cut into the walls of the canal) would resist rotation (Shillingburg and Kessler, 1982, p.15). Unfortunately, they may weaken the root. The problem is intensified when a prefabricated post-composite resin core system is used, as the prefabricated posts are generally round. Newburg and Pameijer (1976) found that these post-core systems performed poorly when resisting torque forces. The addition of two self-threading pins (5) improved the resistance to the torque forces to levels not significantly different from those of the cast post-core system. As pins may be damaging to the dentine (2.4.5), it is preferable that the rotational forces be resisted by remaining tooth tissues. This is an additional reason for retaining all sound supragingival tooth structures. Newburg and Pameijer (1976) also found composite only post-cores to be inadequate in resisting tensile, shear and torque forces.
As mentioned earlier (2.4.3.2), it is advisable to place the gingival margin of composite resin crowns 0.5 to 1.0 mm above the gingival crest, particularly because of the problems with finishing in the gingival area. A post composite resin crown can represent an exception to this rule.

If all the supragingival tooth structures are missing, adequate retention may be provided by a parallel-sided, serrated post (1). The resistance against torque forces may be provided by a modification of the rootface. This should not be in the form of narrow, deep keys, which could weaken the root (Rosenstiel, 1967), and may make the light activation of the composite resin inside them difficult (2.4.9.2). Rather it should be in the form of a step in the rootface.

The rootface, as well as the root canal, are then lubricated. The parapost is placed but not cemented, and the composite resin core is built about it of a conventional or hybrid composite resin. The surface veneer of the composite resin crown is of microfilled composite resin and is placed with a crown form. When, after the cure, the direct composite resin post crown is removed, the rootface is accurately impressed in the composite resin of the root aspect of the crown. The crown can now be very accurately finished and highly polished with aluminium oxide disks (6) prior to its cementation.

With light-activated composite resins, composite resin post crowns may be fabricated using this method when the rootface is at the gingival margin, as there would be problems with the cure subgingivally. Using chemically-cured composite resins, it is possible to venture farther in the apical direction, but apart from the disadvantages of the chemically-cured composite resins (1.3.4),
the problems with maintaining a dry field gradually increase.

It is possible to enhance some mechanical properties of composite resins by a "secondary cure", whereby the composite resin, 5 minutes after the start of the light cure, is exposed to dry heat of 125 degrees Celsius. The composite resin post crown fabricated by the above method lends itself to this treatment. Wendt (1987a, 1987b) found that this secondary cure increased the diametral tensile strength, hardness and resistance to wear (as tested by "a moderately abrasive carborundum wheel"). The optimum length of the exposure to heat was found to be 7.5 minutes (Wendt, 1989). This secondary cure unfortunately also increased the marginal discrepancies with some composites (7, 8), and the statement "gaps at the gingival margin...would be filled by the cementing medium and would not be a problem" (Wendt, 1987a) needs to be considered with caution. These discrepancies are probably a result of polymerisation shrinkage and depend on the level of polymerisation. Kanca (1989) showed that in fact the secondary cure (as measured by the hardness of the samples) only accelerates the rate of polymerisation and does not significantly influence its final level. However, it may be argued that it is preferable for a crown to have all its marginal discrepancies present at the moment of cementation, rather than have them gradually develop after the cementation.

Clinical recommendations. Not every endodontically-treated tooth to be crowned with a direct composite resin crown needs a post-core. When it is indicated, the system combining a parallel-sided, serrated prefabricated post with a composite resin core appears particularly suitable for direct composite resin crowns.
PRODUCTS:

(1) Parapost. Whaledent International, New York, NY, USA.

(2) Adaptic core resin. Johnson and Johnson Dental Products Co., East Windsor, NJ, USA.

(3) Endodowel. Sybron Corp., Romulus, Mich., USA.


(5) TMS Minim. Whaledent Inc., New York, NY, USA.


(7) P-30. 3M Dental Products.

(8) Occlusin. Coe Laboratories.
2.4.7 Etching.

2.4.7.1 Etching of enamel. Dental enamel is the most highly mineralised tissue of the human body. By weight, it consists of approximately 97% inorganic material. By volume, the inorganic material represents about 86%, water and organic material 12% and 2% respectively. The organic material is made up of soluble and insoluble proteins and peptides (Fejerskov and Thylstrup, 1986, p. 50). The inorganic material is hydroxyapatite in the form of crystals, which are 25 to 39 nm thick, 45 to 90 nm wide and their length probably extends from the enamel-dentine junction to the surface (ibid., p. 68, 69). For the purposes of etching and bonding, the enamel crystals are rather conveniently organised into rods, or prisms. The prisms extend throughout the thickness of enamel and their average diameter is about 4 to 5 micrometres (ibid., p. 64). At the enamel-dentine junction, odontoblast processes pass a short distance into the enamel and are called enamel spindles (ibid., p. 81). Enamel tufts and enamel lamellae arise at the enamel-dentine junction, and both consist of insoluble protein (ibid., p. 77-80). The prisms in the inner half to two thirds of the enamel follow a wavy course, which is highly irregular, particularly at the cusp tips and incisal edges. In the outer third of the enamel their course is fairly straight, perpendicular, or at a "slightly acute" angle to the surface (ibid., p. 75, 65).

All surfaces in nature tend to seek equilibrium at the lowest possible energy state. Thus the enamel of the tooth surface in the natural condition tends to be fully reacted. It can be made more reactive by the application of acids.
Since the early 1950's phosphoric acid preparations had been used in industry to increase the adhesion of paint and resin coatings to metal surfaces (Buonocore, 1975, p.63). The first report on the use of phosphoric acid in the chemical modification of the enamel surface was published by Buonocore (1955). In this in vivo experiment a 30-second treatment of the enamel surface with 85% phosphoric acid increased the duration of retention of a drop of acrylic filling resin from the average of 11 hours (for untreated surfaces) to over 1,070 hours (at the time of the report 50% of the drops were still in situ).

Other acids have since been tested. Strong mineral acids tend to produce rapid, non-selective decalcification, the reaction is difficult to control and the acid is very irritating to the soft tissues. If they are used in low concentrations, the acids may become quickly depleted and repeated application is required (Buonocore, 1975; p. 66). Weak acids, or chelating agents, may require a clinically impracticable length of application (Gwinnett and Buonocore, 1965). Some acids have been found to provide for higher bonding strengths than 50% phosphoric acid (Brauer and Termini, 1972). However, in that particular study carried out on bovine enamel, the application of acids was more complicated and, as Buonocore (1975, p. 70) pointed out, the bonding was tested after only a 24-hour immersion in water, which may not have been sufficient time.

Currently the most commonly used acid etchants are based on phosphoric acid. It comes in the form of aqueous solutions or as gels (usually coloured). The main advantages of the gel are its ease of placement, and better control throughout the etching. The
disadvantage may be thought to be its lack of penetration owing to its higher viscosity. Several studies have shown this not to be a serious concern. Brannstrom, Nordenwall and Malmgren (1978) studied the resin impressions of etched surfaces after removing the enamel by decalcification. They found no significant difference in their appearance if the enamel was etched for one minute with 37% phosphoric acid liquid (1) or 50% phosphoric acid gel (2). Brännström, Malmgren and Nordenwall (1982) found no significant difference in the appearance of the impressions of enamel etched with 37% phosphoric acid liquid (1) and 50% phosphoric acid gel (2) for 15 seconds. Tagami, Hosoda and Fusayama (1988) found no significant difference in tensile bond strength obtained on enamel surfaces etched with 40% phosphoric acid aqueous or gel etchant (3). However, unlike the gel etchant, the aqueous etchant required a strong wash (0.20MPa of water pressure) to remove amorphous deposits. Tagami, Hosoda and Fusayama (1988) also found that, while there was no significant difference in the tensile bond strength obtained on surfaces etched with the gel etchant for 20 seconds or for 40 seconds, the failures in the first group tended to be interfacial, while in the latter group cohesive. Babarav, Cardash, Filo and Helft (1988) found, when comparing the appearance of enamel surfaces etched for 1 minute by a liquid etching agent (4) and by a gel etching agent (4), that, if the agents were mechanically agitated with a brush, a similar penetration of the enamel was observed. Without the mechanical agitation, the gel produced a slightly wider and deeper penetration of the enamel, but with large areas of less affected enamel present.

The etchant removes pellicle and debris from the surface, makes
the surface more reactive, improves the wettability and increases the surface area upon which the polymer may attach (Charbeneau, Cartwright, Comstock et al., 1981, p. 313).

The hydroxyapatite of enamel, when attacked by phosphoric acid, is dissolved and forms monocalcium phosphate monohydrate, which precipitates on the etched enamel and, because of its high solubility in water, it is completely washed away in the clinical situation. A concentrated acid solution dissolves less hydroxyapatite (as this is protected by early formation of the precipitate), while at low concentrations of the acid, dicalcium phosphate dihydrate is probably formed, which "would not be washed away completely in a clinical situation" (Chow and Brown, 1973). Consequently, the most effective concentration of the phosphoric acid appears to be around 40%.

This is in agreement with the previous study by Gwinnett and Buonocore (1965) and with the study by Nelson, Till and Hindig (1974). Soetopo, Beech and Hardwick (1978) found the maximum bond strength with acid concentration in the region of 10-30%, where there was maximum enamel dissolution. Zidan and Hill (1986) studied several concentrations of phosphoric acid and found the 35% concentration achieved the greatest surface loss. However, they also found this had little bearing on the actual bonding strength (with the exception of the 0.5% concentration where the strength was significantly weaker), and most of the failures occurred in the resin. Etching of enamel produces three distinct patterns:

a. Prism cores are preferentially removed, creating a so-called honeycomb pattern (this is the most common pattern).

b. The peripheries of the prisms are removed, leaving the cores
relatively unaffected.

c. A more random pattern, with the type 1 and type 2 patterns often adjacent, together with patterns unrelated to the prism morphology (Silverstone, Saxton, Dogon and Fejerskov, 1975).

Galil and Wright (1979) added two more types, which are usually found in the cervical part of the crown. Type 4: pitted enamel, possibly associated with prismless enamel. Type 5: flat and smooth enamel, possibly associated with enamel which had previously received fluoride treatment (or in patients who resided in naturally high fluoride regions).

Previously it was thought that type 1 was caused by acids, while type 2 was caused by chelators (Poole and Johnson, 1967), but Gwinnett, Buonocore and Sheykholeslam (1972) found type 1 and type 2 patterns caused by one acid solution. Poole and Johnson (1967) and Sharpe (1967) suggested that the etching pattern depends on the orientation of the crystallites (and therefore prisms), with type 1 produced by the attack of the acid parallel to the long axes of the prisms, and type 2 produced by the attack perpendicular to the long axes of the prisms. Silverstone, Saxton, Dogon and Fejerskov (1975) found all three patterns to occur on both smooth and occlusal surfaces. Unfortunately, they did not state the relative frequency of the etching patterns on these different surfaces (as the direction of the prisms in the cuspal areas is rather irregular).

Martin and Bryant (1984a) found the type of the pattern related to the direction of the prisms. Of particular significance for the composite resin crowns was their find that the subsurface enamel
exhibited a typical "honeycombed appearance", with abundant sites for the mechanical retention of the resin tags, and that the bevelled enamel exhibited the same kind of etching pattern. However, they pointed out the difficulties of preparing the bevel in certain areas and stressed the importance of avoiding the extension of the margin onto the cementum or dentine of the root surface. They also stressed that prolonged etching should be avoided.

The way the etching agent is applied appears to be of importance. The Council on Dental Materials and Devices (1978) warns against rubbing the enamel during conditioning. Hormati Fuller and Denehy (1980) found that while rubbing a cotton pledget containing 37% phosphoric acid etchant (1) over the enamel surface for 60 seconds did not significantly decrease the shear bond strength obtainable (compared with the specimens where the etchant was only once "dabbed on"), the etch pattern as examined by SEM appeared less sharp, with the prism peripheries shorter and more blunted. Bates, Retief, Jamison and Denys (1982) found no statistically significant differences in tensile bond strength to enamel surfaces etched with 37% phosphoric acid etchant for 60 seconds, regardless of whether the etchant was applied by rubbing, dabbing or without mechanical agitation. However, where rubbing was used the prism peripheries were obscure, resulting in a more uniform etching and it is interesting to note the tensile bond strength achieved on the rubbed surfaces was the strongest, although the difference was not statistically significant. Ben-Amar, Baharav, Liberman and Nordenberg (1988) studied the influence of "continuous brushing acid-etch technique" on microleakage. They found that while this technique (consisting of a continuous circular motion of the brush
under light pressure) did not reduce the microleakage associated with the cavities etched with the liquid etchant, it significantly reduced the microleakage of the margins etched with the gelled acid etchant. Baharav, Cardash, Pilo and Helft (1988) found that when the etchant (both liquid and gel) were applied by "rubbing" with a brush, greater decalcification of the enamel resulted, as observed by SEM.

Views on the optimal length of etching are changing. Buonocore (1955) originally washed the acid off after 30 seconds. Later, extended etching times were recommended (Ibsen and Neville, 1974, p. 43; Albers, 1979) with the most usual etching time being 60 seconds. More recently a number of studies have indicated that this time can be substantially shortened.

Brännström, Malmgren and Nordenwall (1982) found no significant difference in the appearance of the resin impressions of enamel surfaces etched with 50% phosphoric acid gel (2) for 15 seconds and for 60 seconds.

Bates, Retief, Jamison and Denys (1982) examined the effect of 30-second, 60-second, and 120-second applications of 37% phosphoric acid on the tensile bond strength of a composite resin to the enamel. They found no significant difference, even though SEM showed that "a more pronounced etching effect was produced by a 120-second etch".

Barkmeier, Shaffer and Gwinnett (1986) found "essentially no difference in the type of enamel etch pattern" produced by etching for 15 and 60 seconds with 37% phosphoric acid conditioning gel. There was also no significant difference in the shear strength of bonding of composite resin cylinders onto enamel surfaces etched for
15 and 60 seconds.

While the above studies were carried out in vitro, Eidelman, Shapira and Houpt (1984) found that after one year the rate of retention of sealants placed with 20-second etch was comparable to that obtained with "conventional etching times".

Tagami, Hosoda and Fusayama (1988) found that while there was no significant difference in the bonding strength (tensile) obtained after 20-second or 40-second etching with 40% phosphoric acid gel (3), the 20-second etch group failures were almost all of the adhesive type, while the 40-second etch group failures were almost all cohesive. With 40% phosphoric acid aqueous solution, they found the "bond strength markedly decreased when the etching time was increased from 10 to 40 seconds. Strong washing, however, recovered the bond strength to the original level." This they ascribed to an amorphous deposit which obliterated etching irregularities, but which was removed by strong washing (0.20 MPa of water pressure applied for 15 seconds).

The matter of washing is somewhat controversial. Bates, Retief, Jamison and Denys (1982) found no significant differences in the tensile strength of the bond of composite resin Concise (5) to enamel which was etched for 30 seconds (37% phosphoric acid, applied by dabbing) and then washed for 5, 10 or 30 seconds. The composite resin was applied without a "low viscosity bonding resin". They also found no significant difference in the tensile strength of the bond among the groups, where the etching agent was applied for 30 seconds by dabbing, rubbing or with no agitation, and where the etching agent was applied by dabbing for 30, 60 or 120 seconds. In addition, it also appeared that 30 second salivary contamination of
the etched surface was effectively removed by a 5-second wash. However, the authors warned against extrapolating the results of their "in vitro study directly to the clinical situation", and pointed out that if the number of specimens in each test group had been "appreciably larger, some of the nonsignificant differences may have been statistically significant". Even though the mean strengths they achieved (13.8 MPA to 20.7 MPA) fall within the normal range of tensile bond strengths (2.4.8.2), the relevance of their study may have been greater if they had used an intermediate, unfilled resin.

Mixson, Eick, Tira and Moore (1988) found that shear bond strength did not significantly differ among groups where the composite resin was bonded onto enamel surface etched with a Scotchbond Gel Etchant (6) and then washed for 10, 20 and 30 seconds with water/air spray, or for 10, 20, 30, and 60 seconds with water only. A significantly lower bond strength was achieved with a 60-second water/air spray. SEM evaluation showed in this specimen patches of etched enamel that were "flattened". (The pressure of both water and air were 0.28 MPA.) The authors commented on factors other than time which can influence the amount of water used (water pressure, number of operatories, blockage in the syringe tip and even the time of year) and suggested that it would be desirable to establish the rinse volumes necessary.

This they did in the following year, finding that there were no statistically significant differences in shear bonding strength obtained on enamel which, after etching, was washed with 2, 5, 10, 15, or 25 mls of water (Mixson, Eick, Tira and Moore, 1989). SEM evaluation of the etched enamel showed complete surface cleansing of enamel washed with 2 or more ml of water. They also found no
statistically significant differences between groups with varied air pressure (0.14 MPa and 0.28 MPa) and water pressure (0.07 MPa, 0.14 MPa and 0.28 MPa). However, the rinsing times doubled if the water pressure was decreased from 0.28 MPa to 0.07 MPa, if 5 or more ml of water had to be delivered. On the basis of this, the authors recommended the calibration of individual air/water syringes.

Rinse volumes should also take into account the size of the rinsed area. A preparation for a composite resin crown would certainly require a larger amount of water than a Class V cavity. The size of the bonded area in the study by Mixson, Eick, Tira and Moore (1989) was 2 mm x 3 mm, and they recommended 2 to 5 seconds of washing per tooth surface. It seems reasonable to use 20 seconds of total washing time for a composite resin crown.

The effect of fluoride treatment is generally thought to increase the resistance of enamel to acid attacks. Brännström, Nordenwall and Malmgren (1978), studying the resin impression of the surface irregularities produced by a 60-second etch with a 37% phosphoric acid liquid etchant (1), found no significant difference caused by fluoride varnish Duraphat (7) pretreatment of enamel (the length of application was not indicated). This is surprising, especially in view of Sharpe's finding (1967) that micrographic appearance shows no difference between mild acid attack and true enamel caries. Lehman and Davidson (1981), using a profilometer, found that a two-minute exposure to a fluoride application solution substantially increased the resistance of the enamel to 50% phosphoric acid attack. In fact, in some areas the enamel was so resistant that "even after a 3 minute etching period, practically no material is removed."
Kafalias and Patel (unpublished) found that bonding strengths to fluorosed enamel were significantly lower than bonding strengths to normal enamel, when 37% buffered orthophosphoric acid (1) was applied for one minute. They also found that etching of the fluorosed enamel for two minutes significantly increased the bonding strength, while a further increase of the etching time to three minutes did not have a significant effect on the bonding strength.

Deciduous teeth were thought to require longer etching times owing to a more extensive presence of prismless enamel (Ripa, Gwinnett and Buonocore, 1966). However, Nordenwall, Brännström and Malmgren (1980), once again evaluating resin impressions of the surface irregularities produced by 37% phosphoric acid liquid etchant (1) on deciduous enamel, found no significant difference between the results of a 15-second and 60-second etch of deciduous teeth. The deciduous teeth even appeared to etch better than permanent teeth. However, as the authors pointed out, the observations were made on central areas of buccal and lingual surfaces, where prismless enamel is not always present (Ripa, Gwinnett and Buonocore, 1966). The authors also found that young permanent teeth (mean age 13 years) produced better etching results (statistically significant), when etched for 15, rather than 60 seconds. This situation was reversed for old permanent teeth (mean age 77 years).

The influence of age on the effectiveness of etching (as measured by dissolved calcium) was not found to be statistically significant by Shay, Lloyd, Panhans and Bates (1988), who also failed to find a statistically significant influence of race (white
versus American black) on the enamel solubility. They did find, however, that the enamel of molar teeth was significantly less soluble that that of other teeth.

In the mouth, etched enamel, if uncovered by resin material, rapidly remineralises. Buonocore (1955) noted that after removal of the acrylic drops (in vivo bonded onto phosphoric acid etched enamel), the etched area appeared opaque and white, but after a few days their "appearance returned to normal". Arana (1974) found in vivo that after 48 hours the process of "remineralisation" (as judged by appearance) is essentially complete, and that it is faster with young people (his study, however, involved only four subjects). Kastendieck and Silverstone (1979) studied the process of remineralisation both in vivo and in vitro (exposing extracted and then etched teeth to the patient's own oral fluid). They found partial remineralisation in vitro and a "high degree of remineralization of etched regions in vivo".

If phosphoric acid etchant is allowed to contact soft tissues, a mild chemical burn may occur. Even if untreated, it will resolve in a few days (Ibsen and Neville, 1974, p.46).

2.4.7.2 Etching of dentine. Dentine consists of only 70% by weight of inorganic material - this again is mainly hydroxyapatite, forming small crystals, which are "up to 20 nm in length. Their width is somewhat less and the thickness may be up to 3.5 nm." (Mjör, 1986, p. 90-91). They are "randomly scattered and embedded in an organic matrix" (Buonocore, 1975, p.102). For the composition of a dentinal wall, as relevant for etching (and bonding), the percentages by volume are more important and they are approximately
as follows: inorganic portion 52%, organic portion (mainly collagen) 24% and water 24% (Mjör, 1986, p. 91).

"Unlike the biologically nonvital enamel, dentine should be regarded both as an anatomical and physiological extension of the pulp" (Gwinnett, 1985). Tubules extend through the entire thickness of the dentine - there are 30,000 to 75,000 tubules per mm square near the pulp, 15,000 per mm square near the dentinoenamel junction (Provenza and Seibel, 1986, p. 268). The diameter of the tubules is larger near the pulp where it can reach up to 4 micrometres, while near the dentinoenamel junction it is about 1 micrometre (ibid.). Near the pulp, tubules may represent 80% of the volume of dentine, while near the dentinoenamel junction they constitute only about 4% of the volume of dentine. (Mjör, 1986, p. 94). The tubules' diameter tends to decrease with age. The tubules contain odontoblastic processes. This on the one hand presents the problem of protecting the pulp, and on the other makes the drying of the dentinal wall difficult.

Only in exceptional cases has etching of the dentine been recommended. For example, Gwinnett (1981) considered etching of the sclerotic dentine advisable and stated that acid conditioning opens the tubules for approximately 30 micrometres.

The actual effect on the pulp of acid etching of the dentine is controversial. Lee, Orłowski, Scheidt and Lee (1973) found that neither 50% phosphoric (8) nor 50% citric acid (9) were capable of penetrating 1 mm thick disks of dentine, even when applied for 5 minutes. Macko, Rutberg and Langeland (1978) in their in vivo experiment found that all of the acid-etched -50% phosphoric acid containing 7% zinc oxide (10) - teeth demonstrated histological
pulpal response, even though there was an absence of pain. They used a 60-second etch and the cavities were shallow, but extensive. However, Wang and Hume (1988) found that the dentine was an effective buffer, particularly in buffering acids. Apart from the direct effect of the phosphoric acid on the pulp, it is accepted that etching of dentine not only removes the smear layer from the surface of the dentine, but also the smear layer plugs from the dentinal tubules and widens these tubules (Phillips, Hamilton, Jendresen, McMorris and Schallhorn, 1986). Thus etching of dentine should be avoided as it "allows easier penetration of either toxic chemicals, bacterial metabolites or bacteria themselves" (Hume, 1988).

A different attempt to deal with the problem of bacterial penetration under composite resin restorations was made by Inokoshi, Iwaku and Fusayama (1982), who found in vivo (using dogs as experimental animals) that the etching with 40% phosphoric acid for 60 seconds of all the cavity walls, including dentine, prior to the application of a "new resin" (11) led to only a slight pulpal response and no bacterial penetration. While no pulp inflammation was found in cavities where only enamel was etched and the dentine walls were lined with Dycal (12), the pulpal response in unlined, totally etched cavities was "negligible even when the floor thickness was as thin as 80 or 90 micrometres". However, Torstenson, Nordenwall and Brännström (1982), testing this system on human teeth (using 15 seconds etching), found bacteria accompanied by signs of pulpal inflammation in 24 out of 31 test cavities.

In 1987, Fusayama further commented on this way of treatment and speculated that the pulpal complications are caused neither by
the toxicity of dental materials, nor solely by bacterial invasion, but rather by the pumping action which exists under the restorations which do not adhere to the pulpal wall. He recommended total etching of cavities (including dentine), followed by New Bond (13) and Clearfil-F II (14). According to Fusayama, the etching removes the smear layer and makes the intertubular dentine porous. The resin not only forms tags with the chemical adhesion to the tubular walls, but also impregnates the porous dentine. Consequently, no space exists under the restoration and no pump action can develop. While this sounds plausible, it needs to be said that this way of treatment is not universally accepted (at present).

2.4.7.3 Etching of cementum. Cementum covers the dentine of the root. It can be classified into a cellular and acellular type. The acellular type generally covers the coronal half of the root (Furseth, Selvig and and Mjör, 1986, p. 145). This type of cementum is therefore relevant for direct composite resin crowns. The thickness of cementum increases with age and has been measured at the cemento-enamel junction as being about 50 micrometres in the age group 11 to 20 years and about 130 micrometres at the age of 70 years (ibid., p. 157). While in young persons with healthy periodontium the cementum is subgingival (ibid., 1986, p. 132, 133), it may become an area of concern in direct composite resin crown construction when recession of the gingiva exposes it. It meets the enamel in three different relationships: butt joint (30%), cementum ends short of the enamel (10%), and cementum overlaps onto the enamel (60%) (Furseth and Mjör, 1979, p. 118-9).

Cementum is the least well calcified (and therefore the least
hard) of the mineralised dental tissues. By weight, its inorganic content is approximately 65%. By volume, its inorganic material represents approximately 45%, and consists primarily of hydroxyapatite crystallites similar in size and shape to those of dentine. The organic material represents 28% by volume and its principal component is collagen. Water represents 27% of cementum by volume (Furseth, Selvig and Mjör, 1986, p. 145).

Dental literature dealing with the etching of cementum is extremely limited. Ibsen and Neville (1974, p. 130) recommend the etching of cementum - in the treatment of cervical erosions - with 50% phosphoric acid, for 120 seconds, without elaborating on what effect this etching has on the cementum and how it influences subsequent bonding.

Phair and Fuller (1985) found that their restorations "leaked significantly in cementum", even though they etched the cementum margin. Fusayama and Kohno (1989) found that etching of cementum for 30 seconds with a "gel type" etchant in the class V cavities (in vitro) led to a markedly decreased microleakage. In fact, most of the tested materials showed no microleakage.

Most of the other studies dealing with restorations having a margin apical to the cemento-enamel junction do not etch cementum (Fuks, Hirschfeld and Grajower, 1985; Zidan, Gomez-Marín and Tsuchiya, 1987; Leclaire, Blank, Hargrave and Pelleu, 1988; Blunck and Roulet, 1989).

Etching of cementum would lead to its demineralisation and a relative increase of its collagen content - which perhaps may be of clinical significance in bonding with dentine bonding agents, such as Gluma (15), which can bond to collagen. Indeed, it has been found
that Gluma which uses pretreatment with EDTA has achieved relatively
good results at the gingival cavosurface margins (Zidan, Gomez-Marin
and Tsuchiya, 1987; Blunck and Roulet, 1989).

Unfortunately, a search through the Australian Medline fails to
find studies examining effects on the cementum of different modes of
etching, the bonding strengths to cementum etc. Often the parts of
the cavities apical to the cemento-enamel junction are regarded as
if the margin was in dentine. While this assumption may be valid
for in vitro specimens (which have been instrumented in the
cervical area during the extraction), it may be misleading in
clinical situations.

2.4.7.4 Etching of glass-ionomer cements. The glass-ionomer
cement can be etched to modify its surface to increase the
mechanical retention of the composite resin to it (McLean, Prosser
and Wilson, 1985).

Smith (1988) found that there was no difference between the
effect of 37% phosphoric acid gel and 37% phosphoric acid liquid on
the surface of Ketac-Bond (16) and Ketac-Cem (17). In his study he
also examined the influence of different etching times. He found
that the surface roughness increased during the first 15 seconds of
etching. At 20 seconds surface cracks apppeared and after 30 seconds
of etching the particles of glass became so loose they were lifted
from the cement during the impression procedure.

Taggart and Pearson (1988) found evidence that, with a
10-second etching with 37% phosphoric acid gel (18), there were
subsurface changes in the cement (19). After 30 seconds a large
number of glass particles were lying unattached to the surface. The
acid appeared to have penetrated about 300 micrometres below the surface. They thought the critical time after which there was subsurface damage to be between 10 and 15 seconds of etching and on the basis of this they questioned the benefits of the technique, particularly if the layer of cement is thin.

However Joynt, Williams, Davis and Wieczkowski (1989), evaluating the etching of Ketac-Bond (16) and Ketac-Silver (20) and GC Lining Cement (21), found no evidence of subsurface changes even after a 60 second etch with 37% phosphoric acid gel. Moreover, they found the shear strengths of the bond between a composite resin and the glass-ionomer cements were greatest when the cements were etched for 30 seconds (examined times were 0, 20, 30, 60 seconds). Of the three cements tested, Ketac Silver provided for the highest bond strength. It is worth noting that these shear bond strengths averaged (in both the group with no etching and the group with 20 second etching) around 10 MPa, which is above the range of shear bond strengths of glass-ionomer cements to dentine (Long, Duke and Norling, 1986).

The benefit of the bond between the glass-ionomer cement and the composite resin has been questioned by Garcia-Godoy (1988), who pointed out that if there is a strong bond between the composite resin and the glass-ionomer cement, the polymerisation contraction forces of the composite resin may pull the cement away from the dentinal walls.

This may or may not happen. Chin and Tyas (1988) studied the etching of GC Lining Cement (22), Ketac-Bond (23) and Ketac-Silver (24), and found that if these glass-ionomer cements were etched 5 minutes after the commencement of mixing, the tensile bonding
strengths of composite resin to the cements (1.83 MPa, 2.78 MPa and 2.04 MPa respectively) were lower than the tensile bonding strengths of the cements to the dentine (4.47 MPa, 5.15 MPa and 5.52 MPa respectively). If the cements were etched 15 minutes after the commencement of mixing, the bonding strengths of the composite resin to the cements were increased (to 3.88 MPa, 4.27 MPa and 5.84 MPa respectively), and for Ketac-Silver exceeded its bonding strength to the dentine. The weak link may well be the cement itself with its low tensile strength (Tab.2), which may lead to its cohesive fracture.

Finally, from the work of Sheth, Jensen, Sheth and Versteeg (1989), it would seem that not all glass-ionomer cement surfaces need to be treated in the same way prior to having composite resin bonded to them. They pointed out that, while most experiments deal with glass-ionomer cements which set against a smooth surface, bases in vivo would mostly lack a glass smooth surface. Indeed, they found that when the cements were allowed to set uncovered, the bond strengths of composite resin to them were generally similar whether the cements were etched or not.

The question whether any glass-ionomer cements should be etched can perhaps be answered with a reference to the work of Feilzer, De Gee and Davidson (1987) (2.4.9.1) who studied setting stresses in composite resins. These stresses were directly proportional to the Configuration Factor (the ratio between the bonded and unbonded surfaces of the composite resin restoration), as the flow of the composite resin from the unbonded surfaces relieved the stresses.

If the composite resin increment being placed on top of the glass-ionomer base has a high Configuration Factor (such as in Class
III or V cavities), it will exert a high tensile stress on the base. A danger of the base being detached and possibly of the "pumping action" developing (Fusayama, 1987) exists. It may be prudent not to etch the glass-ionomer base in these instances. If the Configuration Factor of the composite resin increment is low, which is generally the case with the direct composite resin crowns (2.4.9.1), the glass-ionomer may be etched, as the composite resin would flow from its unbonded surface towards it.

However, Feilzer, de Gee and Davidson (1987) studied setting stresses on chemically-activated composite resins (25, 26). The light-activated composite resins tend to shrink towards light (Lutz, Luescher and Oldenburg, 1986). Nevertheless, these authors found, when using a light-activated composite resin (27), that the etching of the glass-ionomer base (23) had reduced the amount of dye penetration. The etching produced mixed results on marginal adaptation. The matter was further studied by Krejci, Lutz and Krejci (1988), who found that the etching of the glass-ionomer base, followed by a light-activated composite, compromised marginal adaptation, and suggested that "in a Class II situation" etching should be avoided.

Glass-ionomer cements Type III may be etched 6 minutes from the start of mixing (Mount, 1989c), and glass-ionomer cements Type II should be given 20 minutes between the start of mixing and etching (ibid.), although for some of them (28) a 24 hour interval would be more satisfactory (Mount, 1989b, 1989c). Light-cured glass-ionomer cement Vitrabond (29) needs no etching (3M, 1988), and this will probably apply to other light-cured glass-ionomer cements as well. Composite resins can bond to Vitrabond chemically (ibid.),
and, preferably, the surface of the adherend in chemical bonding should be smooth (Phillips, 1990).

Clinical recommendations: The following surfaces may be considered for etching during the construction of a direct composite resin crown:

Enamel - it is recommended that the enamel be etched with a phosphoric acid gel of around 40% concentration for 30 seconds, during which time the gel should be continuously brushed. Fluorosed enamel requires a longer period of etching. The gel should then be washed off with a water spray or jet for 20 seconds.

Dentine and cementum - although a matter of controversy, the etching of dentine and cementum is not currently recommended.

Glass-ionomer cements - light-cured glass-ionomer cement needs no etching. Glass-ionomer cement Type II can be etched 20 minutes and Type III 4 minutes from the beginning of the mix. They can be etched with the same phosphoric acid gel used on the enamel, for up to 15 seconds. While controversial, these cements should not be etched if used with light-activated composite resins.

PRODUCTS:

(1) Concise etching liquid. 3M Co., St. Paul, Minn., USA.

(2) Directon conditioner. TP Laboratories Inc., La Porte, Ind., USA.


(4) Esticid. Kulzer, Friedrichsdorf, W. Germany.

(5) Concise. 3M Co., St. Paul, Minn., USA.
(6) Scotchbond Gel Etchant. 3M Dental Products Co.

(7) Duraphat. ICN Pharmaceuticals, GmbH and Co., Eschwege, West Germany.

(8) Enamelite cleanser. Lee Pharmaceuticals, South El Monte, Calif., USA.

(9) Epoxylite cavity cleanser. Lee Pharmaceuticals, South El Monte, Calif., USA.

(10) Nuva-Seal L. D. Caulk Co., Milford, Del., USA.


(12) Dycal. L. D. Caulk Co., Milford, Del., USA.


(14) Clearfil F-II. Kuraray Co., Osaka, Japan.

(15) Gluma. Bayer Dental, Leverkusen, West Germany.

(16) Ketac-Bond. ESPE-Premier Corp., Norristown, Pen., USA.

(17) Ketac-Cem. ESPE-Premier Corp., Norristown, Pen., USA.

(18) 37 per cent phosphoric acid gel. 3M Health Care, Loughborough, Leics., UK.

(19) Chemfill II. De Trey Dentsply, Weybridge, Surrey, UK.

(20) Ketac-Silver. Espe-Premier, Norristown, Pen., USA.

(21) GC Lining Cement. GC International Corp., Scottsdale, Ariz., USA.

(22) GC Lining Cement. G-C International Corp., Tokyo, Japan.

(23) Ketac Bond. ESPE GmbH, Seefeld, West Germany.

(24) Ketac Silver. ESPE GmbH, Seefeld, West Germany.

(25) Silar. 3M Co., St. Paul, Minn., USA.

(26) P10. 3M Co., St. Paul, Minn., USA.

(27) Heliosit. Vivadent, Schaan, Switzerland.

(28) Fuji II. GC Industrial Corp., Japan.

(29) Vitrabond. 3M Health Care Group, St. Paul, Minn., USA.
2.4.8 Bonding.

2.4.8.1 General considerations. The term "bonding" in restorative dentistry and in this treatise is used to describe the attaching of the composite resin to a substratum. It is not identical to the term "adhesion", the relevant meaning of which, according to the Macquarie Dictionary (1981, p. 66) is "the molecular force exerted across the surface of contact between unlike liquids and solids which resists their separation." How bonding is understood, and what part adhesion plays in it, can be explained and summarised as follows:

The forces of attraction at an interface (surface of contact) may be physical or chemical. Of these, the chemical forces are by far the stronger, although the physical forces are considered adequate for most adhesive applications. They, however, act at only very short distances of separation and decrease with the seventh power of the distance. Theoretically, surfaces which are flat at the atomic level would adhere on contact, but at this level practically all surfaces are very rough. When placed in apposition, only the high spots (constituting only a small percentage of the surface) contact, and no perceptible adhesion exists. One way of overcoming this problem is to apply fluid onto the solid surface - the fluid will flow into the irregularities and increase the area of contact. For a liquid to spread over the surface of the solid and fill in the irregularities, "wetting" must occur. While wetting depends on several factors, its potential can be measured by the "contact angle", which is the angle formed by the adhesive (liquid) with the adherend (solid surface) at their interface.
The smaller the contact angle, the better the wetting potential. The contact angle depends on the ratio between the attraction of the molecules of the adhesive to each other and their attraction to the molecules of the adherend. The attraction of the molecules of the adhesive to the adherend depends on the surface energy of the adherend. A typical adherend with low surface energy is Teflon, which would form a high contact angle with many liquids. If the adherend has a high surface energy, the adhesive will form a small contact angle or a zero contact angle, in which case the adhesive can spread until it forms a film only one or two molecules thick.

Two more factors need to be considered here.

The first is the viscosity of the adhesive. High viscosity interferes with wetting as the thick adhesive flows only slowly. If strong attraction exists between the molecules of the adhesive and of the adherend, good wetting would occur regardless of the viscosity of the adhesive - given time. However, in clinical situations this time may not be available. Mere application of pressure would not solve the problem, as a viscous material is apt to entrap bubbles of air.

The second factor is the roughness of the adherend. A rough surface may be expected to enhance the adhesion, as it increases the surface area. However, if insufficient wetting occurs (due, for example, to the high viscosity of the adhesive) pockets of air may be entrapped at the surface, actually decreasing the size of the bonded area and concentrating stresses. Cracks may then propagate from one air pocket to the next ("zipper"). (Ibsen and Neville, 1974, p. 5-17; Gwinnett and Buonocore, 1965; Buonocore, 1975, p.
2.4.8.2 **Bonding to enamel.** The enamel of the tooth surface in the natural condition tends to be a poor adherend. To improve its bonding qualities, both mechanical cleaning and acid-etching are employed. Acid etching also creates microscopic pores and crevices in the underlying enamel. The forces of adhesion are instrumental in filling these microspaces with the adhesive by capillary action. Thus resinous "tags", which can extend into the enamel for up to 15 micrometres (Pahlavan, Dennison, Charbenau, 1976) - even though substantially longer lengths have been reported - are formed. These, after polymerisation, provide the "micromechanical interlocking".

Theoretically these tags are not necessary for adhesion, and indeed in some studies (Zidan and Hill, 1986) it was shown that the length of the tags was of no significance for adequate bonding. However, water is a highly polar compound with a high affinity for the inorganic phase of the enamel. Consequently, the molecules of water (which in the mouth are unavoidable) have a tendency to progressively penetrate into the interface and lead, over the years, to the degradation and eventual failure of adhesion. When this happens even if the restoration is retained the molecules of water can act as a separating medium, providing the pathway for the penetration of oral products interfacially. However, prior to that, adhesive forces augmented by micromechanical interlocking as well as macromechanical factors (resistance form of preparation, pins, etc) can give the restorations years of life.

On completion of etching, the etching agent is washed away and
the enamel air-dried. The need for the compressed air used for this
to be oil-free is well known, as is the contamination test
consisting of blowing onto the surface of a mouth mirror.
Batchelder, Richter and Vaidyanathan (1987) found that the
compressed air which can be "expected in typical dental operatories"
is adequate. Interestingly, they also found that the use of hot air
(50 degrees Celsius) significantly increased the shear strength
values of the bond.

A layer of a "bonding agent" or "intermediate resin" (usually a
low viscosity unfilled resin) is generally applied onto the etched,
dried enamel prior to the placement of the composite resin. However,
whether the bonding agent is really beneficial, is a matter of
some controversy.

Mitchem and Turner (1974), evaluating "eight resin systems"
cured both chemically and by UVL) found that while the values
obtained for the "retentive" (shear) strength for specimens with
unfilled resin were higher than for those without, the difference
was not statistically significant, but the mode of fracture
(adhesive, vs cohesive) implied an advantage for "two-resin systems"
(that is, unfilled plus composite). Rider, Kenny and Tanner (1977)
found that while the use of "enamel bonding agent" had no
significant influence on the immediate tensile bond strength, it did
have a positive influence on both tensile and shear bond strength
when the specimens were thermocycled (15 to 55 degrees Celsius, 2880
cycles) before testing. Lüscher, Lutz, Ochsenbein and Mühleman
(1978) concluded that the use of a low viscosity "sealant" (1, 2)
reduced the microleakage.

However, Jørgensen and Shimokobe (1975) found no difference in
the length of tags produced by unfilled resin and by composite resins. Low and von Fraunhofer (1976) found no significant difference on bonding strength between specimens with and without an intermediate resin layer. They also found the strength did not significantly change when the specimens were stored in 37 degrees Celsius water for one week (they were not thermocycled). Prevost, Fuller and Peterson (1982) found intermediate resin significantly increased shear bond strength and reduced microleakage in some composites and not in others. Prevost, Fuller and Peterson (1984) found no statistically significant difference in tags' regularity and length among tags formed by conventional composite resins, microfilled resins and intermediate resins. Martin and Bryant (1984b) found that a composite resin (3) plus unfilled resin (4) adapted better to both etched enamel and machined grooves on a metal slab than the composite resin alone.

It is not easy to arrive at a conclusion on the basis of these contradictory results of tests, which were all done in vitro. The answer perhaps lies along the following lines:

Bonding strengths achieved immediately after bonding appear adequate for composite resin crowns, if the preparation provides sufficient resistance. The durability of these strengths is a matter of equal clinical importance, and from this point of view the work of Rider, Kenny and Tanner (1977) may be of some significance. They found that the use of intermediate resin reduced the drop in both tensile and shear bond strengths after thermocycling. Results pointing in the same direction were obtained by Martin and Bryant (1984b), who found that the use of an intermediate resin (4) significantly reduced the microleakage after thermocycling. It also
seems reasonable to follow the advice given by Prevost, Fuller and Peterson (1984): "Follow the manufacturer's instructions in regard to the need for an intermediate resin. If there is no guidance from the manufacturer, use an intermediate resin. Its use will not have a negative influence on the restoration."

The mean shear bond strength achieved on enamel was given by Mitchem and Turner (1974) as being 12.92 MPa for a conventional, UV-cured composite resin (5) and 31.46 MPa for a conventional chemically-cured composite resin Adaptic (6); by Rider, Kenny and Tanner (1977) as being 16.29 MPa for a conventional chemically-cured Concise (7); and by Hormati, Fuller and Denehy (1980) (uncontaminated samples; material probably Concise) as being 33.22 MPa to 34.78 MPa.

The mean tensile bond strength was given by Rider, Kenny and Tanner (1977) as being 15.35 MPa for Adaptic (8) and 20.74 MPa for Concise (7), and by Munechika, Suzuki, Nishiyama, Ohashi and Horie (1984) as approx. 18 MPa for a conventional chemically-cured composite resin Clearfil (9). All the above values appear to refer to bonding strengths obtained on transversely cut (or ground) enamel prisms. The tensile bond strength obtained on longitudinally cut enamel prisms was found to be approx. 11 MPa for Clearfil (ibid).

While the strengths of 30+ MPa would be probably considered too high by most authorities, all the above values are useful primarily in laboratory comparisons. They cannot be used to calculate the strength of the "retention" of a restoration in vivo, for the following reasons:

- Owing to the geometry of the preparation, to the relatively low modulus of elasticity of the composite resin, and to the
direction of the external forces, practically at no time would the whole bonded surface resist these forces; there would normally be a combination of forces acting upon the crown; and quite often these forces would exert the peel and cleavage effect to which the adhesives have very poor resistance (Ibsen and Neville, 1974, p. 52-53).

- The cross-head speed of the testing machines varied from 1 mm/min to 5 mm/min, which differs substantially from the speed of loading in clinical situations. The behaviour of adhesive joints in general is "the faster the stronger, up to the limiting brittle strength of the material" (Bryant, 1964). Rider (1977) found that increasing the "punch speed" had significant detrimental influence on the shear strength of the bond, and he suggested that, "enamel-composite system lacks the necessary toughness and ability to absorb energy and therefore has a reduced bond strength at high loading rates."

- And, unfortunately, it is generally true that clinical condition values are usually inferior to laboratory conditions values.

In addition, the following should be considered:

- All the above mentioned values are of chemically-activated composite resins. It may be reasonable to assume that the bonding strengths for light-activated composite resins will be different, because their contraction patterns of the chemically-activated composites and light-activated composites differ (2.4.9.1). The values for bonding strengths of the light-activated composites to enamel do not appear to have been extensively studied, perhaps because the advent of the light-activated composites coincided with
the development of the bonding to dentine and the interest of the profession was focused on the latter problem. However, it appears that the bonding strengths of the light-activated composites to enamel may be lower than those of the chemically-activated composites. Williams and Svare (1985) found that the mean shear strengths of the bond of a light-activated composite resin (10) to enamel ranged from 6.1 MPa to 7.1 MPa.

Intermediate resin is usually applied with a disposable sponge, supplied by the manufacturer, or with a brush - preferably again disposable. The layer of intermediate resin may be thinned with a stream of air, although this should not be overdone. Then the question arises, whether it should be cured before the placement of the composite resin. While once again it is sensible to follow the manufacturer's instructions, Mowery, Klockowski and Davis (1986) found no significant difference in the shear bond strengths achieved by simultaneous or sequential curing of the intermediate resin and composite resin. However, only one composite resin was tested (11).

One additional point needs to be considered in this section: bonding of composite resins to enamel to which composite resin has already been bonded previously (and the restoration failed). A study by Boyer and Hormati (1980) showed that, if the enamel contains resin tags, the new resin would bond to them well, and there is no need to remove the superficial layer of enamel by pumicing or disk ing. As, however, the integrity of the layer of tags cannot be determined clinically, it is better to re-etch the enamel. They did not specify the length of re-etching, but it can be assumed to be normal. It needs also to be added that in clinical situations the
cause of the failure should be determined and, if possible, eliminated.

2.4.8.3 Bonding to dentine. Dentine is much more difficult to bond to than enamel. This is a function of its composition, structure and its biological activity (2.4.7.2).

The work by Barnes (1977a) and Gwinnett (1977) showed that composite resin can penetrate considerable distances (100 micrometres, or more) into the tubules of etched dentine in vitro. Falian, Dexin, Weizhong and Guangming (1989) found that while in vivo the penetration of dentine by resin is much smaller, it is still respectable, with the resin tags 10 to 20 micrometres in length (the text, probably misprinted, talks about "diameter", and from their article it is not clear how the in vivo part of the study was done).

Unfortunately, the effectiveness of these extensions of resin into the tubules is less than certain (Tyas, Alexander, Beech, Brockhurst and Cook, 1988). Torney (1978) found that etching of dentine did not increase the retention (tensile strength) of unfilled or composite resins and that, in fact, a thirty second etch significantly decreased retention.

Finally, there is the problem of the smear layer. This is found on both enamel and dentine after tooth preparation. It is removed from the enamel during the acid etch process (Barnes 1977b). The smear layer comprises both organic and inorganic components and is several micrometres thick. Its thickness depends on the type of instruments used - coarse diamond abrasives, especially if used dry, produce the thickest smear layers (Gwinnett, 1984). Its biological
effect is controversial, and according to Pashley (1984) it can be either considered an "iatrogenically produced cavity liner that reduces dentine permeability", or a "depot of microorganisms and their products". Perhaps the best way of dealing with it is to remove the superficial smear layer and leave the smear layer plugs in the dentinal tubules intact. A commercially available product containing an antiseptic component (12) is designed to achieve this (Pashley, 1984; Brännström, 1984b).

Depending on the authorities consulted, the smear layer will "enhance, detract, or have no effect on the bond strength" (Ishioka and Caputo, 1989). This diversity of opinions is probably due to the fact that the effect of the smear layer on bonding depends on the mode of action of the bonding agent. The removal of the smear layer tends also to reduce the proportion of hydroxyapatite in the dentine surface (White, Beech and Tyas, 1989). This would have an unfavourable effect on the bonding strength of those dentine bonding agents which bond to the inorganic components of dentine, for example Scotchbond LC (13) and Prisma Universal Bond (14) (ibid.; Ishioka and Caputo, 1989). However, the decalcified surface of dentine is favourable for dentine bonding agents which bond via dentine collagen, such as Gluma (15) (White, Beech and Tyas, 1989).

Great efforts have been made to achieve chemical adhesion to dentine. The composite resins are purposely hydrophobic, as in the oral environment a hydrophilic resin would swell and disintegrate. Yet, considering the nature of dentine, the adhesive must be hydrophilic (Tyas, Alexander, Beech, Brockhurst and Cook, 1988). To solve the problems posed by this hydrophilic/hydrophobic interface, products termed "adhesion promoters", "dentine adhesives" or
"dentine bonding agents" have been introduced. These are low viscosity materials which are designed to adhere chemically to dentine and to co-polymerise with composite resins (Tyas, Burns, Byrne, Cunningham, Dobson and Widdop, 1986).

In the 1970's, the first generation of commercially available dentine bonding agents based on the research by Bowen, became available - Cosmic (16) and Cervident (17). The key ingredient was NPG-GMA (addition reaction product of N-phenylglycine and glycidil dimethacrylate), which coupled with calcium in the dentine. The products were unsuccessful clinically, and were withdrawn from the market (Gwinnett, 1985).

In the early 1980's, the second generation appeared represented by products such as Scotchbond (13), where phosphate groups react with calcium, or Dentin-Adhesit (18) based on a urethane-isocyanate system, where covalent bonds between urethane NCO groups and hydroxyl groups in collagen or hydroxyapatite provide bonding (ibid.).

The third generation is represented by products such as Gluma (15), which is an aqueous solution of HEMA (hydroxyethylmethacrylate) and glutaraldehyde. It is hypothesised that the bonding here occurs as follows: the cleanser EDTA (ethylenediamine tetracetic acid) removes the surface smear layer, leaving the plugs in the dentinal tubules intact, glutaraldehyde reacts with collagen, an acrylate group is then bonded to the collagen-glutaraldehyde adduct and the acrylate group also co-polymerises with the composite resin (Munksgaard, Irie and Asmussen), 1985). Another product of this generation is Scotchbond-2 (19), which consists of a primer (HEMA and maleic acid in water) and adhesive (HEMA plus hydrophobic
monomers plus polymerisation initiators). The primer penetrates and removes the smear layer and its HEMA reacts with the dentine, the adhesive bonds HEMA to the composite resin. Tenure (20) contains nitric acid, which removes the smear layer (and also can etch the enamel), aluminium oxalate, which precipitates in the dentinal tubules, PMDM (reaction product of pyromellitic dianhydride and 2-hydroxyethyl methacrylate), which bonds to the calcium of dentine, and NPG-GMA, which bonds PMDM to the composite resin (Tyas, 1989).

Whether dentine bonding agents can be used interchangeably with different composite resins is not entirely clear. Chan, Reinhardt and Boyer (1985) found no significant differences in shear bond strength when a dentine bonding agent (13) was used with three different composite resins, one of which was based on urethane dimethacrylate and two on BIS-GMA. Crim (1989) studied five different composite resins using either their manufacturer's bonding agent or Scotchbond Dual Cure (21). All restorations leaked severely at the gingival margin and there was no significant difference between them. However, Crim used one increment filling to fill class V cavities, which probably contributed to the severity of the leaking. He also measured the penetration of the dye only up to 0.75 mm, which disregarded the differences that may have occurred beyond this limit. Contrary to Crim's results, Robinson, Moore and Swartz (1988), studying microleakage in class V cavities filled in six increments, found that no microleakage occurred when the composite resins were used with the recommended adhesives. Interchanging the adhesive caused microleakage, the character of which suggested it occurred between the composite resin and the adhesive. In view of the above, and of the fact that often it is
impossible to obtain the precise composition of the materials (ibid.), it would seem reasonable to use the dentine bonding agent supplied by the manufacturer of the composite resin, whenever possible.

The large number of different dentine bonding systems means that it is difficult to cover their biocompatibility with one comprehensive statement.

Franquin and Brouillet (1988) tested the biocompatibility of Scotchbond (13) (from their article it is not clear whether it was light-cured or chemically-cured). They found it caused unfavourable pulpal reactions, the intensity of which did not appear to be related to the presence of bacteria. They found these reactions were more severe if the dentinal walls were pretreated with 37% phosphoric acid gel (60 seconds) or with EDTA (30 seconds). Although most of the pulpal lesions improved with time, they recommended that a "biological intermediate cement be used after acid etching of dentinal walls in deep cavity preparations." The article does not mention whether the teeth in the control group (which received IRM restorations) had their dentinal walls pretreated.

Siew, Gruninger, O'Young, Ts'ao and Bowen (1984) studied the biocompatibility of a dentine bonding system. They found that neither its components (ferric oxalate, NPG-GMA, NTG-GMA and PMDM - these are the components of the "PDM type of the dentine bonding agents, such as Tenure and Mirage Bond), nor its extract (from the in situ bonding system), were toxic or mutagenic.

Chohayeb, Bowen and Adrian (1988) studied pulpal response to a "dentine and enamel bonding system" consisting of application in sequence of ferric oxalate, water, air, acetone solution of NPG-GMA
or NPG, acetone, air, acetone solution of PMDM and air. The cavities were then restored with a conventional composite resin (22). They found that teeth treated in this way had no inflammatory response 28 days postoperatively, and that the average response 3 days postoperatively was milder than that of the teeth of the control group (restored with the composite resin without pretreatment), which appeared to indicate the experimental materials provided some pulp protection.

Hörsted-Bindslev (1987) studied "monkey pulp reactions" to Gluma Dentin Bond (23). They found a toxic effect of Gluma where the pulpal wall of the cavity was extremely thin (<0.1 mm) - a major part of the coronal pulp lost its normal structure, but the inflammatory reaction was only moderate. However, a test group where a calcium hydroxide lining (24) was used prior to Gluma showed no significantly different results from the test group without a calcium hydroxide lining, and both of these groups pooled together showed significantly better results than the control group where no dentine bonding agent was used. They also found that there was a significant association between the presence of bacteria and the severity of the inflammatory changes. "Bacteria were found only in a very few cavities pretreated with Gluma Dentin Bond." (Ibid.).

It is apparent that the results are somewhat varied, which is partly the function of the diversity of systems, and partly due to the lack of uniformity of the tests. It would appear a sensible policy to obtain bonding to dentine in deep cavities via the medium of glass-ionomer cements (2.4.8.5), even though the dentine bonding agents are not particularly toxic and in fact are beneficial in so far as they reduce the microleakage.
Dumsha and Biron (1984) found that restorations placed with the use of dentine bonding "leaked" significantly less than the control group (composite only restorations). Their treatment of dentine was similar to that used by Chohayeb, Bowen and Adrian (1988).

Hansen and Asmussen (1985) investigated seven different dentine bonding agents and found that none of them prevented the formation of marginal gaps in dentine only cavities, when measured 10 minutes after polymerisation. However, most of them reduced the marginal gap when compared with composite only restorations, and after water absorption for one day, two of them - Gluma and Superbond (25) produced gap-free restorations.

A tensile bond strength to dentine of 44 MPa has been reported (Council on Dental Materials, Instruments and Equipment, 1987). This is a most encouraging figure. Unfortunately, it does not appear to be contained in any of the three references given as sources.

More realistically Eliades, Caputo and Vougiouklakis (1985), who examined six different dentine adhesives, found the mean shear bond strength to be 2.4 to 12.3 MPa. O'Brien, Retief, Bradley and Denys (1988) found the mean shear bond strength of Gluma (15) to be 8.9 MPa and found this strength not to be adversely affected by storage in physiological saline at 37 degrees Celsius (up to 4 weeks) and thermocycling (250 cycles 5 to 55 degrees Celsius).

The mean tensile bond strengths of five different dentine bonding agents have been found to be 1.7 to 14.3 MPa (Asmussen and Bowen, 1986). Asmussen and Bowen (1987) found the mean tensile bonding strengths of Gluma to be between 1.9 and 13.8 MPa depending on the pretreatment of the dentine.

For the clinical significance of these values, once again the
qualifications mentioned with values of enamel bonding strengths apply (2.4.8.2). There is also an additional consideration: as the values for bonding strengths to dentine are within the range of contraction stresses (Feilzer, De Gee and Davidson, 1987), and the laboratory values are generally obtained on a flat dentinal surface, where contraction does not compete with adhesion, these figures may bear no relation to relative clinical performance (Tyas, Alexander, Beech, Brockhurst and Cook, 1988).

These materials are now in the stage of short-term clinical evaluation.

Doering and Jensen (1985) published a six-month clinical evaluation of a "new photocuring dentin bonding resin" (Scotchbond). After six months, only 2 out of 173 restorations (Class V cavities, without preparation) were lost. Sensitivity to "air" has either disappeared or been reduced. The authors etched the enamel margin, which makes the contribution of dentine bonding towards the retention difficult to assess, and the six-month period does not appear to warrant the statement of the authors, "This study indicates that cervical abrasion areas can now be successfully restored without cavity preparation..."

Ziemiecki, Dennison and Charbenau (1985) found that after one year the loss rate for restorations placed with Scotchbond but without enamel bevel and etching was 24% for Silar and 17% for Silux. They also found a substantial decrease in sensitivity. However, it is not clear what proportion of this decrease occurred in cases where the enamel was bevelled and etched (this was one group of restorations studied).

Tyas, Burns, Byrne, Cunningham, Dobson and Widdop (1986)
published one-year results of a clinical evaluation of 175 Silux (10) and 57 Silar (26) restorations placed with chemically-cured Scotchbond (13) into "buccal or labial, caries free, non-undercut cervical abrasion lesions". 25% of Silux and 46% of Silar restorations had been lost, and there was a progressive increase of marginal discoloration. These restorations were placed by six clinicians - an interesting finding was that one of them experienced nil loss rate. This clinician carried out no trimming of the restorations at the placement visit. This appeared to indicate that the bond obtained by Scotchbond takes hours to develop.

Tyas (1988a) published one-year results of a clinical evaluation of two dentine bonding materials used in the restoration of "non-undercut, Class V abrasion cavities: Creation Bond (27) used with Visar-Fil (28), and Dentin Adhesit (29) used with Silux (10) and Heliosit (30). The cumulative rates of loss after one year were 96%, 93% and 77% respectively. All the remaining restorations suffered from marginal staining. It needs to be noted that no enamel etching was carried out with Creation Bond (while it is recommended by the manufacturer) and no "intensive hot air drying" (as recommended by the manufacturer) was used with Adhesit. However, as the author has pointed out, this study did suggest that Creation Bond was not adequate as a dentine bonding agent and, apart from the lack of universal availability of the facilities for hot air drying required for Dentin Adhesit, there was also the question of its effect on the pulp.

Tyas (1988b) also published a one-year evaluation of Dentin Adhesive (31), Bondlite (32) and Dentin Bonding Agent (33) used in restoration of "Class V no-undercut abrasion lesions". The rate of
loss was 83%, 25% and 33% respectively. Dentine Bonding Agent had the most severe marginal staining, while Bondlite the least severe marginal staining. No trimming or contouring of restorations was carried out until one to four weeks after placement.

Heymann, Sturdevant, Brunson, Wilder, Sluder and Bayne (1988) published a one-year clinical study of two dentinal adhesives - Prisma Universal Bond (34) and Scotchbond (13) - in Class V cervical lesions. The rate of loss was 16% for Scotchbond, and for Prisma Universal Bond varied from 8% to 24% depending on the method of application. It needs to be noted that in this study a bevel was prepared in the enamel and the enamel was etched. The authors also found a statistically significantly higher rate of loss in patients with higher occlusal stresses, in older patients and in cavities in the mandibular teeth (as against those in the maxillary teeth).

Tyas, Burns, Byrne, Cunningham, Dobson and Widdop (1989) published three-year results of a clinical evaluation of 175 Silux (10) and 57 Silar (26) restorations placed with chemically-cured Scotchbond (13), this being a continuation of their previous work (1986). The cumulative loss rate after 3 years was 30% for Silux and 58% for Silar. Compared with the one-year results there was also a further increase in marginal discolouration and 3.5% of Silux restorations were carious. The rate of loss had a tendency to increase in the one to three year period.

A table published in Dental Outlook (Latest Ranking of Dentine Bonding Agents, 1988), containing data from Tyas, gave the clinical loss rate over 12 months of composite resin restorations retained by nine different dentine bonding agents used in restoration of Class V
erosion cavities without the use of enamel etching. The loss rates varied from 96% for Creation Bonding Agent (27) to 18% for Gluma Dentin Bond (23). The loss rate for glass-ionomer Cements (Fuji Type II and Ketac-Fil) was given as 5%.

It appears that from the above the following conclusions can be drawn:

a. While there are a number of "dentine bonding agents" available on the market, at present none of them is capable in its own right of providing durable retention for restorations. Even if a dentine bonding agent capable of it may appear shortly on the market, it will be several years before clinical evaluation of its performance can confirm it.

b. These agents (if used according to their manufacturers' instructions) do provide some bonding to dentine. This contributes to the retention obtained by other means and reduces microleakage and sensitivity.

c. Particularly if only a thin layer of dentine is remaining, it may be prudent to utilise glass-ionomer cements as the media bonding composite resins to the dentine. Glass-ionomer cements have been discussed in a previous section (2.4.4.5), and it has been seen that they have several advantageous characteristics. The bonding of composite resins to glass-ionomer cement linings is often referred to as the "sandwich technique" and will be described in a following section (2.4.8.5).

2.4.8.4 Bonding to cementum. As mentioned earlier (2.4.7.3) the area of etching of and bonding to the cementum has not been extensively examined, and some studies of gingival margins of
restorations would probably deal with both cementum and dentine cavosurface margins.

Kain, Hirsch and Meeker (1983), in studying ways of reducing microleakage at the cervical margins of class V restorations found that all restorations suffered from microleakage at this margin. Significantly less microleakage occurred when composite resin was added to this margin after the restorations were cured and finished (the added composite was refinished with polishing disks).

Phair and Fuller (1985) evaluated the microleakage of three different composites - Concise (3), Cervident (35) and Spectra-Dentin Bonding System (36) in cavities with cementum margins. Two of the composites (35, 36) were supposedly suitable for these kinds of cavities. They found that all restorative materials leaked significantly in cementum and the authors concluded, "The small differences in microleakage...do not offer recommendations for preference..."

Fuchs, Hirschfeld and Grajower (1985) found that the application of two layers of Scotchbond (13) significantly reduced the microleakage at the gingival margin. Unfortunately, 55% of gingival margins still exhibited different degrees of microleakage.

Zidan, Gomez-Martín and Tsuchiya (1987) examined the effectiveness of eight dentine bonding agents and four of their combinations on the marginal gaps (as indicated by dye penetration). They found that marginal gaps were present in 75% of all dentine locations investigated. The most effective single agent was Gluma (37), which produced four out of fifteen restorations gap-free, and the most effective combination was Gluma with Clearfil PII (38), which produced ten out of fifteen restorations free of gaps.
Blunck and Roulet (1989) also found that Gluma (23) and Scotchbond (13) significantly reduced the marginal gaps of composite resin restorations - achieving "acceptable marginal adaptation" in more than 90% of the margin length. Unfortunately, after thermocycling (2,000 cycles between 5 and 55 degrees Celsius) there was a drop to 60% and 43% respectively in this figure.

It would appear that at this stage, in spite of considerable improvements, a satisfactory answer to the problem of bonding composite resins to cementum has not yet been found. It would be prudent, in the construction of direct composite resin crowns, to keep the composite resin short of the cementum and where a lesion exists in the cementum, to restore it with glass-ionomer cement prior to the placement of the composite resin.

2.4.8.5 Bonding to glass-ionomer cement. McLean, Prosser and Wilson (1985) described a clinical technique, based on laboratory studies, for what came to be known as the "sandwich technique". This is where composite resin is bonded to glass-ionomer cement, which is bonded to the dentine. They regarded the cement as a replacement for dentine and chamfered it to the cavosurface margin on the gingival margin of Class V cavities. The mean "three point shear" strength of the composite resin (39) to the glass-ionomer cement (40) in their study was 10.25 MPa if the cement was etched (37% phosphoric acid for 1 minute), or 6.5 MPa if the cement was not etched.

Garcia-Godoy, Draheim and Titus (1988) found the shear bond strength to range for Visio-Molar (41) to GC Lining Cement (42) from 0.4 MPa to 5.8 MPa and for Visio-Molar to Ketac-Bond (43) from 1.2
MPa to 9.0 MPa when comparing non-etched cement with the cement etched for 30 seconds with 37% phosphoric acid.

Hinoura, Moore and Phillips (1987) compared the bonding strengths achieved to glass-ionomer cements with a smooth surface (set against glass), rough surface (roughened with 400-grit silicon carbide paper) and etched surface (37% phosphoric acid for 1 minute) and found that roughening and etching significantly increased the bonding strengths, with etching achieving somewhat higher strengths than roughening.

Causton, Sefton and Williams (1987) found that the bonds achievable to etched glass-ionomer cements (40, 44) were stronger when a layer of unfilled resin was placed between the composite resin and the glass-ionomer cement. They also noted that the cohesive fractures within the cement occurred more than 1 mm from the etched surface. They speculated that infiltration with resin strengthened the etched cement. This appears to be of importance, as due to its low tensile strength (Tab.2), the cement may often be the weakest link.

Hinoura, Onose, Moore and Phillips (1989) studied the influence of bonding agents on the bond strength between glass-ionomer cements and composite resins. It appeared the consistency of the bonding agent had the greatest influence on bonding strength, with the agent of the lowest viscosity achieving the strongest bond. The chemical composition of the agent also played a role in determining the bonding strength, and the authors commented on a need for further investigations of this factor.

Mount (1989a) studied the wettability of twelve bonding agents on surfaces of a glass-ionomer cement (45), as measured by their
contact angles. He found the contact angles were decreased by etching the cement and also by abrading it. For more viscous agents, the abrading needed to be augmented by etching to achieve significant reduction of the contact angle. He concluded that agents with high viscosity seemed unsuitable for use in the "sandwich technique" and also that the best results were achieved when the glass-ionomer cement was roughened before etching.

Mount (1989b) further examined different factors influencing the strength of the union between glass-ionomer cements and composite resins and concluded the main factors were:

a. The tensile strength of the cement. This he found varying from 2.75 MPa for a Miracle Mix (46) to 7 MPa for Ketac Fil (45), with the "lining" glass-ionomer cements closer to the lower end of the range. The cement with higher tensile strengths allowed for higher bonding strengths.

b. Viscosity of the bonding agent and its ability to wet the cement surface, with the failures nearly always adhesive for bonding agents with high viscosity.

c. The volumetric changes of composite resins associated with their curing and with thermal changes, resulting in low strengths achieved with relatively lightly filled microfilled resins, which are less dimensionally stable (Tab.1).

d. Adaptability of the composite resins to the underlying cement. Mount speculated that the incorporation of voids at the interface was the cause of high standard deviations associated with the posterior composites.

The tensile bond strengths achieved in this study ranged from about 0.6 MPa for the combination of Fuji II (47) and Heliosit (48)
to about 7.6 MPa for Ketac-Fil (45) and Visio-fil (49).

Clinical evaluation of the bond between composite resins (10, 50) and glass-ionomer cements (45, 47) was carried out by Tyas, Toohey and Clark (1989). They compared the rate of failure (including both partial and complete losses) of restorations, consisting of glass-ionomer cement overlaid by composite resin, in Class V non-undercut abrasion lesions. They used four techniques: neither enamel nor glass-ionomer etched, glass-ionomer only etched, enamel only etched, both glass-ionomer and enamel etched. The incidence of failures at two years was: 58%, 43%, 35% and 10% respectively.

2.4.8.6 Bonding to composite resins. Bonding to composite resin substrata is of particular relevance for direct composite resin crowns. In their fabrication adequate composite resin restorations may be encountered in situ, and often the construction of a composite resin crown may involve placement of large amounts of composite resin, making the incremental build-up method mandatory.

Causton (1975) found that composite resins bonded strongly to themselves, even if the substratum composite resin matured for 8 weeks in water maintained at 37 degrees Celsius, prior to the bonding. The mean shear bonding strengths in this condition (tested 7 days after bonding) varied from 15.26 MPa to 28.28 MPa.

Forsten and Strömberg (1976) found that the transverse strength of "repaired" specimens was only slightly lower than that of unrepaired specimens of the composite resins (3, 51), with the matrix based on BIS-GMA. A composite resin based on methyl-methacrylate (52) did not bond well to already hardened
material. They ground the substratum surfaces and found the use of intermediary resin had no beneficial influence on the bonding strength.

Similarly, Meeker, Hirsch and Kaim (1983), studying microleakage, found no need for unfilled resin when repairing voids (in vitro) at the cavosurface margins of composite resin (53) restorations.

A different result was obtained by Boyer, Chan and Reinhardt (1984), who examined 11 different composite resins and found that the application of bonding agents (unfilled resins) increased bonding strengths whether the substratum composite resin surface was cut or not.

Application of unfilled resin was recommended also by Eli, Weiss, Littner and Drutman (1986), who found that the specimens more frequently fractured at the interface, when no unfilled resin was placed on the substratum surface. When the unfilled resin was used, fractures occurred more frequently away from the interface. The tensile strength of the samples fractured at the interface tended to be lower than that of the samples fractured away from the interface, which in most cases exhibited strength not significantly different from the cohesive strength of the control group.

Similarly, Chalkley and Chan (1986) found the application of a bonding agent - both chemically-cured and light-cured Scotchbond (13) - reduced microleakage between layers of different light-cured composite resins.

The five above-mentioned studies examined bonding to composite resins which set without access of air, except for the study by Eli, Weiss, Littner and Drutman (1986) which did not make this aspect of
the experiment clear. Particularly during the incremental build-up of a direct composite resin crown, bonding will be done to a substratum of composite resin which was cured while exposed to air. Eliades and Caputo (1989) examined the composition of the oxygen-inhibited layer which exists on the surface of light-cured composite resins which were cured while exposed to air, and found that it is primarily composed of catalyst-free monomer. Bonding strength was improved if a layer of compatible unfilled resin (unpolymerised) was interposed. However, the thickness of the resin rich layer thus produced was irregular which could lead to failures on loading. The highest interlayer strength was achieved when the inhibited layer was removed with acetone.

The study by Eliades and Caputo (1989) appears to contradict the results achieved by Chin, Tyas and Goldman (1987), who generally obtained higher strengths when bonding the same materials in the presence - rather than absence - of air. It would be interesting to know what values Eliades and Caputo would have obtained had they included in their study an additional group with the substratum cured in the absence of air.

Contamination of the substratum surface with saliva reduces bonding strengths considerably. The detrimental effect of saliva is significant even when the contamination lasts only 1 second (Chalkley and Chan, 1986). Treatment of the contaminated surface (after spray washing and drying) with a bonding agent increases the bonding strength (Chiba, 1983). Chiba found the bonding strength very low if the saliva contamination was of 1 week or 3 months duration and recommended reduction of the surface, followed by application of a bonding agent.
Chiba's recommendation was not supported by Eli, Liberman, Levi and Haspel (1988), who found that while saliva contamination (of 48 hours duration) did decrease the tensile/shear bonding strength of their samples, the difference was not significant. The grinding of the contaminated surface reduced bonding strength considerably, although the subsequent application of the bonding agent improved the strength to the levels achieved in the group where the contaminated samples were treated with the bonding agent only. However, from their study the value of intermediate resin itself cannot be determined as there was no group where unground substratum was not treated with bonding agent.

The finding that mechanical intervention such as cutting or grinding, reduces the bonding strength is consistent (Boyer, Chan and Torney, 1978; Boyer, Chan and Reinhardt, 1984; Söderholm, 1985; Eli, Liberman, Levi and Haspel, 1988). This has been attributed to the exposure of the filler particles, and the deprivation of these particles of their silane coupling agent by the mechanical procedures (Boyer, Chan and Torney, 1978). This explanation was supported by Söderholm (1985) who found that treatment of the cut surface with silane solution greatly increased the bonding strength.

The exposure of the filler particles and the loss of the silane coupling agent would undoubtedly reduce the bonding strength to composite resins which have been in the mouth for some time. In addition, it appears that the strength of the bond decreases with the age of the substratum composite resin. Boyer, Chan and Torney (1978) found that significantly weaker bonding was achieved with the samples where bonding was done 24 hours after curing of the substratum, compared with those where the bonding was done 7 or 30
minutes after curing. Boyer, Chan and Reinhardt (1984) found there was a general trend for bonding strength to decrease with age. They attributed this fall in strength to the decreased number of unreacted methacrylate groups (due to the increased level of polymerisation), with the consequent decreased possibility for primary bonding.

At times, the substratum and the subsequent composite resins may be different. The bonding strength between chemically-cured composite resins (3, 53, 54), and a UV-cured composite resin (55) was studied by Chan and Boyer (1983). They found the UV-cured composite resin to be a relatively poor substratum for chemically-cured composite resins providing for a mean tensile bond strength of 14.1 MPa, compared with the mean tensile bond strength of 25.8 MPa achieved between different chemically-cured composite resins. The bonding strength of the UV-cured composite resin to chemically-cured composite resin substrata was not significantly different from those achieved between chemically-cured composites. However, as the UV-cured composite resins are considered obsolete, they will be generally found as substrata.

Bonding strengths between chemically-cured and VL-cured composite resins were studied by Chin, Tyas and Goldman (1987). An interesting finding was that when the substratum was VL-cured composite resin Estilux (56) to which a chemically-cured composite resin Silar (57) was bonded, the bond's mean transverse strength was weak (10.2 MPa), if the substratum was cured without protection from the air. If the substratum was "matrix-set", the bond strength was satisfactory (36.9 MPa). This was explained by the existence of an oxygen-inhibited layer on the surface of VL-cured substratum, which
remains uncured after the addition of a chemically-cured composite resin. However, once again, the chemically-cured composite resins are likely to be encountered as substrata. While the bonding strengths of a light-cured Silux (58) to a chemically-cured substratum Miradapt (59) were lower (31.1 MPa and 31.8 MPa for matrix-set and air-set substrata respectively) than those achieved when a VL-cured composite resin Silux was bonded to a VL-cured composite resin Estilux (47.3 MPa and 53.1 MPa for matrix-set and air-set substrata respectively), the strengths achieved appear adequate from the clinical point of view.

The bonding strengths between composite resins with different fillers were studied by Chan and Boyer (1983), who found microfilled resins (26, 60) to be "excellent substrates", which they attributed to the "large concentration of resin in these materials".

Chalkley and Chan (1986) found that there was only "minimal microleakage" when microfilled composite resins (10, 61) were bonded to a conventional composite (62), provided the substratum composite was etched, rinsed and then treated with chemically-cured or light-cured Scotchbond (13).

Chin, Tyas and Goldman (1987), when bonding a VL-cured microfilled composite resin Silux (58) to a conventional (small particles) composite resin Estilux (56), found the mean transverse bond strength to be higher (being 47.3 MPa and 53.1 MPa for matrix-set and air-set substratum respectively) than that achieved when Silux was bonded to itself (being 36.3 MPa and 36.4 MPa for matrix-set and air-set substratum respectively). Bonding a chemically-cured microfilled composite resin Silar (57) to a chemically-cured hybrid composite resin Miradapt (59) produced
bonding strengths which appeared adequate (being 57.2 MPa and 43.6 MPa for matrix-set and air-set substratum respectively).

The bonding of composite resins was studied by Chalkey and Chan (1986), who found that the highest degree of leakage in their experiment occurred when composite resins with chemically different matrices were combined. However, the same combination yielded different results, depending on which composite resin was cured first. This they attributed to the number of reactive molecules remaining on the surface of the polymerised substratum.

Puckett, Holder and O'Hara (1988) found that a urethane dimethacrylate composite resin Oclusin bonded poorly to BIS-GMA based composite resins P30 and Herculite.

Similarly, Tjan and Glancy (1988a) found that a urethane dimethacrylate based composite resin Heliosit (67) bonded poorly to a number of BIS-GMA composite resins, achieving mean tensile bonding strength of only 2.1 MPa and 4.7 MPa, while the mean tensile bonding strengths of a number of combinations of BIS-GMA based composite resins varied from 8.9 MPa to 17.2 MPa in their experiment.

2.4.8.7 Bonding to porcelain. A composite resin crown may occasionally be constructed on a tooth containing a porcelain inlay. Several kits for bonding composite resins to porcelain (normally used for repairs of porcelain crowns) are available. They generally employ silane coupling agents to obtain bonding in the porcelain-composite resin interface. Roughening the porcelain surface adds mechanical retention and significantly increases bond strength (Wood, Jordan, Way and Galil, 1986). Porcelain can be roughened with green stones (ibid.), but as these are frequently not
entirely round and concentric, which may result in the "hammering
effect" (Grundy, 1985), coarse diamonds (Bailey, 1989) may be
preferable.

The surface of porcelain may also be made more retentive by air
abrasion with $\text{Al}_2\text{O}_3$ particles, or by etching (Bertolotti, Lacy and
Watanabe, 1989). The etching may be done with 9.5% hydrofluoric acid
gel (68) applied for four minutes (ibid.). As hydrofluoric acid is
very corrosive, the use of rubber dam is mandatory and it is wise to
use a caulking material (69) to secure the seal. However, "one must
remember that hydrofluoric acid gives off a fume which irritates
respiratory passage..." (Ultradent Products, 1989). Bertolotti, Lacy
and Watanabe (1989) found that etching the porcelain with 1.23%
acidulated phosphate fluoride gel (70) for ten minutes produced
bonding strengths not significantly different from those achieved
when the etching was done with the hydrofluoric acid.

When using a "porcelain repair kit" it is important to adhere
to the manufacturer's instructions, and with some systems (71, 72)
bonding strengths in excess of 11 MPa (shear) may be obtained
(Pratt, Burgess, Schwartz and Smith, 1989). Unfortunately, the
longevity of the bond appears unsatisfactory and these strengths are
not maintained. Pratt, Burgess, Schwartz and Smith (1989), who
studied 6 different systems, found that the average decrease in the
shear bonding strength after a 3-month storage in a 37 degree
Celsius water bath was nearly two thirds (64.63%) of the original
(48 hour) strength.

2.4.4.8 Bonding to gold. Gold (generally found in the form of
an alloy as a cohesive gold restoration would nowadays be a rarity)
is a noble metal, the term denoting its chemical stability (Phillips, 1982, p. 371). While in the oral cavity it is a desirable characteristic, it makes the possibility of chemical bonding remote. Products which are claimed to provide bonding of composite resins to gold often yield discouraging results (Eames, Rogers, Feller and Price, 1977). More recently, Clinical Research Associates Newsletter (1990) reviewed 12 different metal adhesives, of which 11 claimed bonding to any dental metal. Of those which can be used intraorally, some required tin-plating of noble metals, or sand blasted surfaces. While both tin-plating and sand blasting can be performed intraorally (Bertolotti, Lacy and Watanabe, 1989), the review pointed out that metal adhesives have "unknown long term strength of adhesion".

The surface of the gold inlay in the tooth which is being prepared for a direct composite resin crown will generally be rended roughened, which may provide a certain amount of mechanical retention for the composite resin. Wood, Jordan, Way and Galil (1986) found that a gold surface roughened with a green stone "bonded with a heavily filled (73% by weight) resin (73) provided shear strengths...comparable to conventional acid-etch enamel bonding by means of a lightly filled (28 % by weight) resin (74)...". However, they tested their specimens after only 24 hours of dry storage. A small inlay, separated from the envisaged gingival margin of the crown by an expanse of enamel, may be tolerated. A large inlay which cannot be easily removed, and which extends to the area of the crown's margin, may indicate an alternative mode of treatment.
2.4.4.9 **Bonding to amalgam.** Occasionally amalgam restorations may be found in anterior teeth. If the amalgam restoration is in the vicinity of the gingival margin of the crown, it may be reduced without being removed in its entirety, and the contour rebuilt with a glass-ionomer cement. Glass-ionomer would bond into the amalgam.

Aboush and Jenkins (1989) found the tensile bonding strength of a glass-ionomer cement (75) to amalgams (76, 77) to be in the range of 7 to 8 MPa. The composite resin would bond to the glass-ionomer cement (2.4.8.5) and its margin may stay within the glass-ionomer cement if this, in its turn, reaches the vicinity of the cemento-enamel junction. The beneficial effect of the fluoride-releasing glass-ionomer cement at the crown margin has been mentioned earlier (2.4.4.5).

If an amalgam restoration is surrounded by an expanse of sound enamel (such as would be the case with the palatal "cingulum pits"), composite resin can be bonded to it via the medium of products such as Panavia (78), or preferably Cover-Up II (79). Cooley, McCort and Train (1989) found the mean shear bond strengths achieved with these products to diamond-prepared amalgam to be (after thermocycling) 3.23 MPa and 6.87 MPa respectively.

However, there is generally a definite value in not complicating procedures unnecessarily. If the amalgam restoration is reduced and the cavity thus created filled with composite resin, the shear strength of the composite resin filling this cavity will resist external forces acting parallel to the surface of the tooth. The shear strength of composite resins does not appear to have been extensively studied, but Drummond and Khalaf (1989) published values for shear strength of 15 "Maryland (acid etch) bridge resin
cements". The "weight percent filler" of these cements ranged from 15 to 80 % and their shear strength from 44.4 to 70.2 MPa. Providing the values of shear strength for composite resins fall within this range, the total shear strength obtained by this procedure would be greater than that obtained by bonding to amalgam. The lack of bonding to the surface of the amalgam, will be compensated for by the shear strength of the bonding of the composite resin filling the cavity to the enamel of the cavity walls.

Clinical recommendations. The following surfaces may be encountered during the construction of a direct composite resin crown:

Enamel - reliable bonding of adequate strength can be obtained. It is advisable to apply a layer of low viscosity "intermediate resin" on the etched, washed and dried enamel prior to the application of the composite resin.

Dentine - a number of "dentine bonding agents is available". It is essential to adhere to the manufacturers' instructions. As there is some question regarding their effect on the pulp, they should not be applied on the pulpal floor of very deep cavities. The longevity of the dentine bond is at present uncertain.

Cementum - it is advisable to keep the gingival margin of direct composite resin crowns short of cementum. If this is not possible, glass-ionomer cement should be interposed.

Glass-ionomer cements - it is advisable to roughen the cement and etch it, although this is not indicated for light-cured glass-ionomer cements. A low viscosity "intermediate resin" should be
used. Stronger cements allow for higher bonding strengths.

Composite resins - it is beneficial to avoid mechanical preparation of the substratum, if possible. The use of intermediate resin is recommended. The increments need not be of the same composite resin, but they should have matrices of the same kind.

Porcelain - the porcelain substratum should be mechanically roughened. It may be also air-abraded, or etched, preferably with acidulated phosphate fluoride gel. Several kits for bonding to porcelain are available and it is essential to adhere to the manufacturers' instructions. The longevity of bonding to porcelain appears at this stage unsatisfactory.

Gold - a small gold inlay surrounded by an expanse of enamel may simply be roughened prior to bonding. A gold inlay extending onto the cementum should be removed, even if it is small, and the cavity thus produced filled with a glass-ionomer cement type II. Medium or large gold inlays should be removed, and, if this is not possible, a direct composite resin crown may not be indicated.

Amalgam - small or medium amalgam restorations surrounded by an expanse of enamel should be reduced below the adjoining surface and the cavity thus created filled with the composite resin. Small or medium amalgam restorations extending onto the cementum should be reduced and the cavity filled with a glass-ionomer cement type II. Large amalgam restorations should be removed.
PRODUCTS:

(1) Cosmic Bond. De Trey GmbH, Wiesbaden, West Germany.
(2) Johnson & Johnson, East Windsor, NJ, USA.
(3) Concise. 3M Center, St. Paul, Minn., USA.
(4) Enamel Bond. 3M Centre, St. Paul, Minn., USA.
(5) Nuva-Seal/Nuva-Fil. L. D. Caulk Co., Milford, Del., USA.
(6) Adaptic Bonding Agent/Adaptic. Johnson & Johnson, New Brunswick, NJ, USA.
(7) Concise Enamel Bond/Concise. 3M Co.
(8) Adaptic Enamel Bond/Adaptic. Johnson & Johnson Ltd.
(9) Clearfil Bond System-F. Kuraray Co., Ltd., Okayama, Japan.
(10) Silux. 3M, St. Paul, Minn., USA.
(11) Prisma-Bond/Prisma-Fil. L. D. Caulk Inc., Milford, Del., USA.
(12) Tubulicid. Dental Therapeutics AB, Nacka, Sweden.
(13) Scotchbond. 3M, St. Paul, Minn., USA.
(14) Prisma Universal Bond. Caulk-Dentsply, Milford, Del., USA.
(15) Gluma. Bayer, Leverkusen, West Germany.
(17) Cervident. S. S. White, Holmdel, NJ, USA.
(18) Dentin Adhesit. Vivadent USA, Inc., Amherst, NY, USA.
(19) Scotchbond 2. 3M, St. Paul, Minn., USA.
(20) Tenure. Den-Mat Inc., Santa Maria, Calif., USA.
(21) Scotchbond Dual Cure. 3M Dental Products, St. Paul, Minn., USA.
(22) Adaptic. Johnson & Johnson, Dental Products, New Windsor, NJ, USA.
(23) Gluma Bond. Bayer AG, West Germany.

(24) Procal. 3M, St Paul, Minn., USA.

(25) Superbond. Sun Medical.

(26) Silar. 3M, St. Paul, Minn., USA.

(27) Creation Bond. Den-Mat International, USA.

(28) Visar-Fil. Den-Mat International, USA.


(31) Dentin Adhesive. Kulzer, West Germany.


(33) Dentin Bonding Agent. Johnson & Johnson, USA.

(34) Prisma Universal Bond. Caulk-Dentsply, Milford, Del., USA.


(36) Spectra-Dentin Bonding System. Den-Mat, Inc., Santa Maria, Calif., USA.

(37) Gluma (Experimental). Cutter Dental, Berkeley, Calif., USA.

(38) Clearfil FII. Kuraray Co., Osaka, Japan.


(40) Ketac Cement. Espe GmbH, Seefeld/Oberbay, West Germany.

(41) Visio Molar. ESPE GmbH, Seefeld/Oberbay, West Germany.

(42) GC Lining Cement. G-C International Corp., Tokyo, Japan.

(43) Ketac Bond. ESPE GmbH, Seefeld/Oberbay, West Germany.

(44) Ketac Silver. Espe GmbH, Seefeld/Oberbay, West Germany.

(45) Ketac-Fil. Espe GmbH, Seefeld/Oberbay, West Germany.

(46) Fuji II and Lumi Alloy. GC Industrial Corp., Tokyo, Japan.

(47) Fuji II. GC Industrial Corp., Tokyo, Japan.

(49) Visio-Fil. Espe GmbH, Seefeld/Oberbay, West Germany.

(50) Silux. Getz, Teledyne Getz, USA.


(52) TD 71. Dental Fillings Ltd., England.


(54) Prestige. Lee Pharmaceuticals, South El Monte, Calif., USA.

(55) Nuva-Fil. L. D. Caulk Co., Milford, Del., USA.

(56) Estilux. Kulzer Australia Ltd., North Sydney, NSW, Australia.

(57) Silar. 3M (Aust.) Pty Ltd, Pymble, NSW, Australia.

(58) Silux. 3M (Aust.) Pty Ltd, Pymble, NSW, Australia.


(60) Isopast. Vivadent, Buffalo, NY, USA.

(61) Durafill. Kulzer Inc., Irvine, Calif., USA.


(63) Visio-Dispers. ESPE-Premier Corp., Norristown, Pa., USA.

(64) Visio-Fil. ESPE-Premier Corp., Norristown, Pa., USA.

(65) Micro-Fine. L. D. Caulk Co., Milford, Del., USA.

(66) Prisma-Fil. L. D. Caulk Co., Milford, Del., USA.

(67) Heliosit. Vivadent (USA) Inc., Tonawanda, NY, USA.

(68) HF gel. Ultradent, Salt Lake City, Ut., USA.

(69) Ora Seal. Ultradent, Salt Lake City, Ut., USA.

(70) APF. Sultan, Englewood, NJ, USA.

(71) Scotchprime Ceramic Primer. 3M, St. Paul, Minn., USA.

(73) Phase II. Reliance Orthodontic Products, Itasca, Ill.,
    USA.

(74) Endur. American Ormco, Glendora, Calif., USA.

(75) OpusFil W. Davis, Schottlander and Davis, London, UK.

(76) Amalcap. Vivadent, Schaan, Liechtenstain.

(77) Dispersalloy. Johnson and Johnson, East Windsor, NJ, USA.


(79) Cover-Up II. Parkell.
2.4.9 Placement and curing.

2.4.9.1 Placement. During polymerisation, the density of composite resins increases, with a corresponding decrease in their volume. This "curing shrinkage" varies depending on both the filler and the matrix of the composite resin (1.3.1, 1.3.2), but is mostly within the range of 2 to 3% vol. (Goldman, 1983).

The reduction in the volume means that in unbonded restorations "contraction gaps" develop. If the composite resin restoration is bonded to the walls of the preparation, a competition between the shrinking stress, cohesive tensile strengths of the substratum and the adhesive, and the bonding forces develops.

The shrinking stress is considerable and has been calculated (Davidson and de Gee, 1984) to be 32.2 MPa for Silar (1) and 68.2 MPa for Concise (2), thus being the highest of the competing forces. If no other factors were involved, this competition would ultimately lead to the failure of the weakest links, namely to the failure of the bond of the composite resin to the dentine (as this is the weakest of the values for shrinking stress, tensile strength of the dentine and the bond strength of composite resin to the dentine) and to a fracture of the enamel (as the tensile strength of the enamel is the weakest of the values for shrinking stress, tensile strength of the enamel and the bond strength of the composite resin to the enamel) (Tab.1, 2.4.8.2, 2.4.8.3).

The additional factor which comes into play is the "flow" of the composite resin. While curing, the composite resin is capable of "flowing" from its free (unbonded) surface, thus assuming a reduced volume. Fortunately, the material does not appear to be damaged
internally by this flow, which has been demonstrated by the equal tensile strengths of material cured under either free or restricted conditions (Davidson and de Gee, 1984).

The magnitude of the actual shrinking stress depends on the shape of the restoration. Feilzer, de Gee and Davidson (1987) studied the development of shrinkage stress in samples of chemically-activated composites (1, 3) with various ratios between bonded and free surfaces. They found that the lower this ratio, which they called "Configuration Factor", the lower the contraction stress and the slower its development. It appeared that the ratio equal to 1.0 (which existed when the bonded and free surfaces of the samples were equal in size) was critical, in so far as the samples with the Configuration Factor of below this value developed shrinkage stresses "lower, or just reaching into the range of reported bond strengths of dentine bonding agents". It also appeared that, in general, the shrinkage stress is independent of the volume of the restoration.

This has important implications for direct composite resin crowns. The Configuration Factor for a direct composite resin crown will always be less than 1.0, as its inner, bonded surface is always smaller than its outer surface which is free.

Feilzer, de Gee and Davidson (1987) used specimens of the same geometric shape (cylinder) to examine the development of shrinkage stress. It would seem, however, that this stress depends also on the geometric shape of the restoration. The shrinkage stress is relieved by the flow of the composite resin from the free surface, and the size of this surface is therefore of crucial importance for the magnitude of the actual shrinkage stress.
The size of the free surface depends on two variables. One is the ratio of the bonded surface to the free surface (the Configuration Factor). If this ratio is set, the size of the free surface would obviously be determined by the second variable, which is the total size of the surface of the restoration. Fortunately, this variable (which would be increasingly unfavourable in shapes approaching that of the sphere) is favourable in the composite resin crowns.

It needs to be said that the abovementioned studies (Davidson and de Gee, 1984; Fellzer, de Gee and Davidson, 1987) were dealing with chemically-activated composite resins (1, 2, 3), which according to Phillips (1991, p.221) "shrink toward the centre of the bulk of material". The illustrations of Lutz, Krejci, Luescher and Oldenburg (1986) also show shrinkage toward the centre of the bulk of the chemically-activated composite.* However, light-activated composite restorations begin to polymerise on the surface nearest to the light. In this area the first loss of volume occurs, and towards this area (that is, towards the light) the restoration

*In the view of this author, the direction of shrinkage of the chemically-activated composites may depend on the circumstances. Shrinkage will be towards that region of the composite resin where the loss of volume due to the polymerisation occurs first. This will be the region with the higher temperature. In a specimen on a slab, or in a deep Class I cavity it may be the centre of the bulk. In large, flat increments, placed in vivo, it may be the surface of the preparation, which is likely to have a higher temperature than the air of the surgery.
shrinks (Lutz, Luescher and Oldenburg, 1986).

Shrinkage occurring at the gingival margin would be more harmful if directed away from the margin, as this could lead to the creation of a gap at the cavo-surface margin. The following measures may minimise the gap:

a. The incremental method of placement is preferable to bulk placement. While shrinkage stress is independent of volume, the total amount of shrinkage obviously depends on volume. With the incremental method of placement, subsequent increments compensate for the shrinkage of the previous increments. The final shrinkage of the restoration placed in increments is equal to the shrinkage of the last increment, plus the shrinkage of all the increments which occurs during the polymerisation that continues for at least one day after the application of the light (Leung, Fang and Johnston, 1983; Atmadja, 1986).

b. The build-up and the cure (2.4.9.2) should begin at the gingival margin and proceed incisally. With light-activated composites, the use of "laterally light reflecting wedges" (4) (that is, wedges which can change the direction of light and, therefore, of the curing shrinkage), is advisable. If these wedges are placed at the gingival margin, the shrinkage will be towards this margin and not away from it (Lutz, Krejci, Luescher and Oldenburg, 1986; Lutz, Krejci and Oldenburg, 1986). It is important that the incremental build-up proceeds from the gingival margin incisally, even if chemically-activated composites are used. In this way the Configuration Factor of the increments will be kept below 1.0. If the gingival increment were placed last, a competition could develop between the penultimate increment and the gingival margin of the
preparation, where generally poor bonding can be expected (Zidan, Gomez-Marin, Tsuchiya, 1987). Hansen (1986) found no significant difference in the size of the contraction gap in his two-increment restorations, whether the gingival increment was placed first, or last. However, because of the shape of the cavity and of the increments, the Configuration Factor of the gingival increment in both cases was greater than 1.

There are additional reasons why the incremental method should be used. The placement of the composite resin in too thick a layer may mean incomplete curing (2.4.9.2).

Furthermore, it is advantageous to combine the mechanical properties of the traditional and hybrid composite resins with the aesthetic properties of the microfilled composite resins (1.6.1). This is of particular relevance for direct composite resin crowns used in the treatment of fractured teeth, where the bulk of the missing tooth structure is replaced with a conventional or hybrid composite resin - which may be retained with the aid of pins - and surfaced with a layer of microfilled composite resin. In these instances, if the traditional or hybrid composite resin is of more dentine-like colour (yellowish-reddish), and the microfilled composite resin more enamel-like (primarily translucent), a more natural looking composite crown will result (Larson, 1986). Additional aesthetic considerations may argue in favour of incremental build-up, as the natural teeth may have deep characteristic stains or crack lines, which are easier to imitate during incremental build-up.

During the build-up, the shape of the contralateral and adjacent teeth have to be taken into consideration. It is important
that the crown be built with correct "emergence profiles". These profiles generally tend to be straight, and overbuilding in these areas is detrimental to the gingival and periodontal health (Croll, 1989). The lingual surfaces of the anterior teeth may be somewhat convex (in the gingival third), and the distal surfaces of canines tend to be concave (ibid.). The build-up of the proximal surfaces is facilitated by the placement of wedges and a matrix. While wooden wedges may provide adequate mechanical support for the matrix, prevent "overhangs" and separate slightly the teeth, "laterally light reflecting wedges" (4) are preferable if light-activated composite resins are used.

Special instruments (5) are available for the build-up. Composite resin will adhere to them less than it would to metal instruments. However, small amounts of composite resin may adhere, from time to time, to any available instruments. It is important to remove these small amounts immediately, otherwise increasingly large amounts will adhere. In addition, it may be felt that it would be helpful if the instruments were lubricated.

Tjan and Glancy (1988b) examined different "lubricants" for this purpose. They found that the use of alcohols (ethanol and isopropanol) was inadvisable as it led to whitish stains and sometimes to adhesive fractures (during tensile tests). Dentine bonding agents achieved inconsistent results, even when they were from the same manufacturer as the composite resins - Bondlite (6) used with Herculite (7) did not significantly reduce the strength of the specimen, but Adhesit (8) used with Helimolar (9) did reduce the strength significantly. The best results were achieved with bonding resins from the same manufacturer as the composite resins -
Command resin (10) used with Herculite and Helibond (11) used with Heliomolar - which did not affect significantly the strength of the specimens. The surface of the increment may be smoothed by a brush, moistened with the bonding resin. However, overenthusiastic use of the bonding resin would lead to a reduced degree of "loading" of the composite resin, which may affect its mechanical and physical properties (1.3.1).

After the placement and curing (2.4.9.2) of the gingival increment, the middle increment, which includes the contact points, is placed. Unless the anterior teeth are generally present with diastemas (and it is not intended to close these diastemas), the build-up of contact points is often difficult and requires proper wedging to provide slight separation of the teeth. If there is an occlusal contact between incisors in the centric occlusion, the contacting region should be built of a hybrid composite, because of the better mechanical properties of the hybrid composite resins (1.5.1.4, 1.6.1). It should always be of a hybrid composite or canines. As pointed out earlier (2.4.8.6), the composite resins used in the same crown build-up should have compatible organic phases. The incisal increment is placed and cured last.

A number of authors (2.2.2) have used the bulk placement method, placing the composite resin with a crown form. The advantages of this method are the speed and ease of the placement. The disadvantages have been implied above. Primarily they are:

a. A large polymerisation shrinkage, which may lead to the creation of the gingival gap.

b. Questionable cure of the deeper parts of the crown.

c. Inability to create some aesthetic effects.
In the opinion of this author, the bulk method of build-up is justified only in cases where speed is paramount - such as with children, mentally handicapped patients, etc. In these cases, while the whole of the composite resin is placed in one increment, if a light-activated composite resin is used, at least the curing should start at the gingival margin, and the translucent wedges with laterally reflecting cores (4) should be used.

2.4.9.2 Curing. How long should the exposure time be? Lutz, Krejci, Luescher and Oldenburg (1986) found when using light reflecting wedges that the highest degree of polymerisation was achieved with the 60-second exposure.

Elsewhere, the adequate length of irradiation depends on several factors. Generally, little increase in the degree of polymerisation (as measured by hardness) of the surface of the composite resin can be expected when exposure time is increased from 20 to 40 or 60 seconds (Swartz, Phillips and Rhodes, 1983; Leung, Fan and Johnston, 1983; Atmadja, 1986).

Below the surface, the degree of polymerisation increases with increased exposure time. At the depth of up to 1 mm below the surface most of the increase is not significant (Atmadja, 1986). However, it needs to be kept in mind that the light will not always be applied perpendicularly to the surface. In fact, on the proximal surfaces the application is parallel to the surface, and consequently the thickness of the composite resin which the light has to cure may be considerable.

Thicker layers of composite resins require longer periods of irradiation (Leung, Fan, and Johnston, 1983; Swartz, Phillips and
Rhodes, 1983; Chan and Boyer, 1985; Atmadja, 1986; Standlee, Caputo and Hokama, 1988). However, it needs to be noted that Atmadja (1986) found that "The degree of cure is maximised with greater certainty by reducing the thickness of the increment than by increasing the exposure time."

Microfilled composite resins may require more irradiation than macrofilled and hybrid composite resins (Atmadja, 1986; Standlee, Caputo and Hokama, 1988). Atmadja (1986) suggested that the increments of the microfilled composites should not exceed 2mm in thickness. Swartz, Phillips and Rhodes (1983) found inadequate curing at 3mm depth, even when a macrofilled composite resin (12) was irradiated for 40 seconds.

Darker shades may require more irradiation (Swartz, Phillips and Rhodes, 1983; Atmadja, 1986).

If the composite is cured through the enamel, the length of the cure should be extended (Standlee, Caputo and Hokama, 1988).

Increased filler levels have been found to increase the depth of cure for macrofilled composite resins (Li, Swartz, Phillips, Moore and Roberts, 1985) and for microfilled composite resins (St. Germain, Swartz, Phillips, Moore and Roberts, 1985). Atmadja (1986) recommended, "the more heavily filled the microfilled composite resin, the thinner should be the increment", but his study examined only two microfilled composite resins (13, 14).

An increase in the distance of the light tip from the surface of the composite resin would affect the cure negatively. However, as Atmadja (1986) found little significant effect when this distance was increased from 0 to 4 mm, this factor is more relevant for posterior teeth.
Tjan and Dunn (1988) measured the diameters of the light tips of seven different light generators and found they varied between 6 and 8 mm. If the area to be cured is larger than the area irradiated by a stationary light tip, the tip has to be moved. The curing may be performed either by continuously moving the tip over the cured area, or by curing spot by spot. Clinical Research Associates (1984) found the deepest and most homogeneous cures were achieved by slow rotation of the light source. Similar results were achieved by Neo, Denehy and Boyer (1986). Kelsey, Shearer, Cavel and Blankenau (1987) recommended that the light be held stationary, as with this method they achieved a higher degree of polymerisation. However, the total exposure time they used was 30 seconds, which for the thickness of their sample (3.0 mm) may not have been enough.

Clinical Research Associates (1984) recommended that the length of the scanning be adjusted for the size of the area. If, for example, the area to be cured is twice the area of the light source, the length of the exposure is doubled.

While this is undoubtedly a sound suggestion generally, it needs to be kept in mind that the shape of a composite resin crown causes a part of the irradiated area to be outside the crown, and the preferential treatment given to the gingival margin means there will be overlapping of cured areas on the crown. Consequently, it seems reasonable to suggest that the scanning time be so adapted that the least cured region receives an adequate period of irradiation.

Tjan and Dunn (1988) found that different light generators, when applied for 60 seconds, caused rises in temperature from 4.10 to 14.60 degrees Celsius directly at the light emitting tip. The
range of temperature increases was 2.10 to 11.80 degrees Celsius under a 1 mm thick dentine barrier. Under a 2 mm dentine barrier, the range was from 1.30 to 7.45 degrees Celsius. The thickness of dentine in anterior teeth varies from about 0.7 mm (palatal surface of upper central incisors at the incisal end of the pulp) to nearly 3 mm (lingual surface of the upper canines near the cemento-enamel junction) (Shillingburg and Grace, 1973). Fortunately, near the gingival margin of the crown, where the most prolonged application of the light source is required, the thickness of the dentine varies less and does not appear to be less than about 1.6 mm (proximal surface of the lower incisors (ibid.)). To this, the thermal insulation provided by the enamel has to be added (Tab.1).

On the other hand, the polymerisation of composite resin is an exothermic reaction (Masutani, Setcos, Schnell and Phillips, 1988), adding to the rise of temperature. Thus, in their study of various combinations of composite resins and activator lights, the total temperature increases ranged from 8.3 to 22.0 degrees Celsius (measured in the centre of the specimen). Most of the total rise in temperature appears to occur within the first 30 seconds of exposure to the light (ibid.).

Zach and Cohen (1962) found that the increase in the intrapulpal temperature of teeth prepared with an air turbine (238,000 rpm) without water cooling was 15 degrees Celsius in 25 seconds of preparation (started from an "air jet" cooled tooth). While theirs was an in vivo experiment, where the vital pulp undoubtedly somewhat reduced the magnitude of the thermal changes, it would be prudent to exercise care with the prolonged applications.
of light during the curing of the composite resins.

If a prolonged application of light is required, it may be advisable to divide the irradiation into periods separated by a pause. Stanford, Leung, Knoepfel and Stanford (1984) found that if the total exposure time was adequate, there was no significant difference in hardness values between samples cured by continuous or sequential (two or four intervals) irradiation. Masutani, Setcos, Schnell and Phillips (1988) irradiated their specimens in two periods and found that the rise in temperature was much lower during the second period. However, the periods were 60 seconds long and the second one began "after the temperature of the specimen had returned to 24 degrees Celsius". It seems that more research into this problem is needed before more specific recommendations can be given.

Light can also be applied with a light source using a large diameter tip, where the cure area is up to 15 mm wide (Clinical research associates, 1984). A satisfactory degree of cure can be achieved with the large diameter tips (Neo, Denshy, Boyer, 1986). These tips make scanning unnecessary, as one stationary application of the tip from the labial aspect and one from the lingual aspect will cover the whole crown.

2.4.9.3 Colour aesthetics. Often several shades of the composite resin are needed for a direct composite resin crown. However, at least two shades should be chosen: gingival and incisal (Larson, 1986). The gingival part of the crown is generally of a more yellowish-reddish hue, while the incisal (particularly in young persons, where enamel has not been lost through attrition) is more
translucent and may appear blue violet or grey (ibid.). Differently
coloured composites can be easily applied when the incremental
technique is used. The mixing of composite resins on a pad is not
recommended, as it leads to increased porosity (Goldman, 1983).

Colour modifiers (also called "tints") and opaquers can be used
to adjust the hue, value, and chroma. There are several brand names
of tints and opaquers available (15, 16, etc.). It is also possible
to prepare them individually by mixing powders from a porcelain
staining kit with unfilled resin (Biederman, 1982). They can be
placed between the bonding agent and the composite, or more
superficially, but a layer of composite resin should cover them as
their wear resistance is inadequate (ibid.)

For the appearance of the crown, value is more important than
hue (Larson, 1986). Value can be increased by using a white tint,
which will also increase the opacity. To decrease the opacity of
the appearance, a thicker layer of translucent composite resin may
be added (Mc Innes-Ledoux, Zinck and Weinberg, 1987). Value may
also be increased by addition of the dominant hue of a higher value,
which will also increase the chroma (Larson, 1986). Value may be
decreased by adding grey (Biederman, 1982). Both value and chroma
may be decreased by adding the complementary colour, which will also
increase the potential for unfavourable metameric effects (Larson,
1986).

Colour modifiers may also be used to imitate characteristic
spots and crack lines. Fine lines may sometimes present a problem.
A technique is available to produce fine dark lines (Bass, 1990).
During the incremental build-up a V-shaped groove is created in
uncured composite. The appropriate modifier is placed in it. The
composite is then squeezed together, prior to curing. It is important to cover the tint with a thin layer of composite resin (Biederman, 1982). While the crown should harmonise with the adjacent and contralateral teeth, the individual characterisation should not be overdone.

**Clinical recommendations.** In the construction of direct composite resin crowns the incremental method of build-up is recommended. The build-up of the contour of the preparation should be done with conventional or hybrid composite resins. The areas of contact in centric occlusion and the areas of contact during canine or group guidance on canines should be built of a hybrid composite resin. Elsewhere, the surface layer should be of a more translucent microfilled composite resin. It is essential that composite resins used on the same direct composite resin crown have compatible matrices. The use of translucent wedges with laterally reflecting cores is recommended. It is important to cure gingival areas first and to take care not to overheat the pulp during the cure.

**PRODUCTS:**

(1) Silar. 3M, St. Paul, Minn., USA.

(2) Concise. 3M, St. Paul, Minn., USA.

(3) P-10. 3M. St. Paul, Minn., USA.

(4) Luciwedge MK II. Hawe Neos Dental, Gentillino, Switzerland.

   Premier Cure-Thru Reflective Curing Wedge System. Premier Dental Products Co., Norristown, Pa., USA.

(5) Temple Composite Instruments. Premier Dental Products Co.,
Norristown, Pa., USA.

(6) Bondlite. Kerr/Sybron, Romulus, Mich., USA.

(7) Herculite. Kerr/Sybron, Romulus, Mich., USA.

(8) Adhesit. Vivadent (USA) Inc., Tonawanda, NY, USA.

(9) Heliomolar. Vivadent (USA) Inc., Tonawanda, NY, USA.

(10) Command resin. Kerr/Sybron, Romulus, Mich., USA.

(11) Heliobond. Vivadent (USA) Inc., Tonawanda, NY, USA.

(12) Prisma-Fil.


(14) Durafill. Kulzer Australia Ltd., North Sydney, Australia.

(15) Esthetic Design System. 3M, St. Paul, Minn., USA.

2.4.10 Finishing and Polishing.

2.4.10.1 Sealing the gingival margin. The gingival margin is usually the weak point of composite resin restorations as far as adhesion and microleakage are concerned. This can be attributed partly to more difficult access to this area and to increased difficulties in maintaining a dry field. However, in vitro studies generally produce the same result - the gingival margin is where the failures occur. Bonding to the dentine (2.4.8.3) and cementum (2.4.8.4) is not as reliable as bonding to the enamel (2.4.8.2). When a competition develops between curing contraction stresses, bonding to the enamel margin and bonding to the dentine margin - the gaps develop at the dentine margin. The gingival margin is the weak point even when it is in the enamel, and it becomes less reliable as the cemento-enamel junction is approached (Zidan, Gomez-Marin and Tsuchiya, 1987). This is because the enamel of this part of the tooth is thinner and is covered by a prismless layer (2.4.3.1).

Asmussen (1985) suggested postponement of polishing of the composite resin restoration for several days (so as not to obstruct the marginal gap with debris), during which the gap would hopefully be closed through the hygroscopic expansion of the composite resin. Yet, at which point should the marginal gap be considered closed? Water sorption may continue for up to 8 weeks, even though most of it occurs during the first two weeks (Pearson, 1979). Disregarding the fact that during this period bacteria may penetrate into the interface, strictly speaking hygroscopic expansion will not lead to the margin being sealed. Although through hygroscopic expansion the composite resin may be put into apposition to the dental
tissues, it will not be bonded to them.

Torstenson, Brännström and Mattson (1985) found in vitro and in vivo that unfilled resin - probably Concise Enamel Bond (1) with a fluorescent additive - penetrated into the marginal gap for up to 2 mm, thus improving the seal. They covered the whole cervical wall of their cavities with the liner (2) to stop the flow of dentinal fluid from the dentinal tubules, which could prevent the penetration of the unfilled resin. They removed excess composite resin with a carver, so as not to obstruct the gap with finishing debris. The authors suggested that the resin drop be drawn along the gap "so that air in the gap can escape". This they achieved by "slowly brushing it laterally from one side to the other".

Kemp-Scholte and Davidson (1988) further elaborated on this method and showed that for the sealing to lead to complete elimination of the gap, the Modulus of Elasticity of the composite resin needs to be relatively low (as the shrinkage of the unfilled resin has to be compensated for by the strain of both the composite resin and the unfilled resin). Fortunately, the surface layer of the direct composite resin crown will generally be a microfilled composite resin, and microfilled composite resins have relatively low Modulus of Elasticity (Bryant and Mahler, 1986).

The hygroscopic expansion which will occur subsequently will partly release the residual strain, and may help to regain the loss of contour which has occurred during polymerisation due to polymerisation shrinkage. In the presence of an undisrupted bond at the cavosurface margin, hygroscopic expansion should not lead to the creation of an "overhang" (Kemp-Scholte and Davidson, 1989). Nonetheless, it is prudent to examine the gingival margins several
weeks after placement, and to refinish them if necessary (ibid.).

Torstenson, Brännström and Mattson (1985) found that the application of the liner (2) outside the cavity facilitated the removal of the excess composite. Nevertheless, great care will have to be taken in the removal of the excess, so as not to damage the extramarginal dental tissues, or the soft tissues. In addition, there may be clinical situations where the removal of the excess composite with a carver and the sealing of the contraction gap may be difficult to achieve - for example at the proximal gingival margins. As it is common clinical knowledge that it is often harder to correct iatrogenically created problems than to treat the original pathological conditions, it is advisable to adhere to the techniques which aim to prevent the formation of overhangs and to minimise the contraction gaps.

These techniques have been elaborated in the preceding parts of this treatise: preparation, which removes the prismless layer and stays wherever possible within the enamel (2.4.3.1), restoration with glass-ionomer cement where the caries extends beyond the cemento-enamel junction (2.4.4.5, 2.4.7.4, 2.4.8.5), wedging with light reflecting wedges (2.4.9.1, 2.4.9.2), incremental build-up starting with the gingival increment first (2.4.9.1) and the light application with the gingival margin cured first (2.4.9.2).

2.4.10.2 Finishing and polishing. After the impregnation of its margin, the finishing of the direct composite resin crown may be carried out. The contour is established, as determined by function and aesthetic considerations, and the surface is rendered smooth, conducive to the next step of polishing (Lutz, Setcos and Phillips,
1983). The objective of polishing is to achieve a "smooth and glossy surface" (ibid.), as plaque material tends to accumulate more readily on rough surfaces (Swartz and Phillips, 1957; Larato, 1972; Shafagh, 1986).

Flat emergence profiles should have been established during the build-up (2.4.9.1). They should be perfected, if necessary, at this stage. The shape of the composite resin crown is finalised. The objective is to restore the original which has been lost through caries or accidents, or to improve on the original such as in the building-up of "peg laterals". Once again it is sensible not to overdo individual characteristic irregularities.

Occlusion usually requires adjustment and should be done as the last procedure of the finishing, as it would necessitate the removal of the rubber dam. The occlusion of the composite resin crown should generally be established to harmonise with the existing occlusion (Wise, 1982).

If large amounts of composite resin have to be removed, this should be done while the rubber dam is in place, as considerable amounts of dust will be generated, not all of which will be removed even by high speed suction. For this bulk excess removal, diamonds with high grinding effectiveness can be used. However, as they may damage both the composite resin and the enamel, their use should be limited to the outer layers of the composite and they should not be used on the resin-enamel interface (Lutz, Setcoos and Phillips, 1983). After the removal of the bulk excess, instruments with finer and finer grit are used, to achieve a smoother and glossier surface.

If polishing disks can be used, the sequential use of disks containing aluminium oxide (3) will achieve a glossy surface with
low surface roughness (Louka and Stillwater, 1982; Reinhardt, Denehy, Chan, Rittman, Heitkamp and Smith, 1983, Grundy, 1985; Abdalla and Hamza, 1985; Tjan and Chan, 1989). The disks come in three sizes and several degrees of roughness, distinguishable by their colour. The "maximum particle size" of the black disks is 67 micrometres, of the dark blue disks 31 micrometres, of the medium blue disks 22 micrometres, and of the pale blue disks 7 micrometres (Grundy, 1985). The disks are eminently suitable for large, flat or convex surfaces, such as the labial surfaces of direct composite resin crowns. Unfortunately, because of the lack of space, the disks cannot be satisfactorily used on proximal surfaces. Because of the scalloped shape of the free gingiva, often even the smallest disks cannot be used on the gingival margins without the danger of injuring the soft tissue. And finally, it is difficult to adapt a rotating disk to a concave surface.

There are several ways of dealing with these difficult areas. On the proximal surfaces, proper wedging should minimise the amount of finishing and polishing needed, but if a small excess exists, it may be removed with coarse aluminium oxide strips, and then smoothed and polished with medium, fine and superfine aluminium oxide strips (4). Patterson and McLundie (1986) found that these strips created a surface on composite resins, "which compared most favourably with that of intact enamel" when examined under the SEM. This result was achieved with both the microfilled composite resin (5) and the hybrid composite resin (6) they tested, even though of the two the microfilled composite resin "consistently acquired smoother surface finishes".

Rigid instruments such as stones, burs, or diamonds, of
suitable shapes, allow accurate application on the gingival margins and on concave areas.

The stones commonly available are green stones (7) containing silicon-carbide (maximum particle size 85 micrometres), and finer white stones (8) containing silicone-oxide and quartz (maximum particle size 32 micrometres) (Lutz, Setcos and Phillips, 1983; Grundy, 1985). Even after short use, stones are rarely perfectly round and concentric. This causes the "hammering effect" which results in surface scoring and subsurface damage. Their abrasive particles barely protrude from the binding and are also less sharp and hard than diamond particles. Consequently, they are less abrasive and tend to "plough" through the composite (Lutz, Setcos and Phillips, 1983). They are likely to dislodge the macrofiller particles and also to "rock loose and destroy" the prepolymerised particles and agglomerated complexes of microfilled composite resins (ibid.). Pratten and Johnson (1988) found a smear layer formed on the composite resin by the white stone (abrasive particles 60 micrometres) (9), which was probably due to the low abrasiveness of the stone.

The Ra (roughness average) of the surface of composite resins (traditional, hybrid and microfilled) was found to be lower when these were finished and polished with 40-micrometre and 15-micrometre diamonds, compared to that achieved with a sequence of 12-fluted and 40-fluted tungsten carbide burs (Lutz, Setcos and Phillips, 1983).

Boghosian, Randolph and Jekkals (1987) found tungsten carbide burs affected a microfilled composite resin (Silux) and a hybrid composite resin (Herculite XR) differently. Both 12-fluted and
30-fluted carbide burs caused a disrupted surface on the microfilled composite resin - fractures, particle dislodgement and fissures. Both 12-fluted and 30-fluted burs created a smooth, flat surface on the hybrid composite resin, smoother than 15-micrometre diamond. These authors speculated that the higher concentration of BIS-GMA in the microfilled resin caused the occlusion of carbide bur flutes. Similarly, Goldstein and Wahnine (1989) found that a carbide bur gave a smoother surface than a diamond when used on a hybrid composite resin (10). Pratten and Johnson (1988) found no statistical difference between Ra achieved with a 12-fluted carbide bur (11, 12) and an extrafine diamond (13), and no significant difference for the two composite resins they studied - one filled to 74% vol (14), the other to 59% vol (15). Both composite resins were hybrid, with the macrofiller being relatively soft porous strontium glass.

Tolley, O'Brien and Dennison (1978) evaluated several methods of finishing composite resin and advised against the use of diamonds "because of the high roughness produced". However, they did not state the grit size of the diamonds they used. This aspect was investigated by Lutz, Setcos and Phillips (1983), who found that a "cavity preparation diamond bur" with the diamond particle size 100 micrometres or more, consistently achieved the highest Ra values on all composites tested (conventional, hybrid and microfilled). On the other hand, a finishing sequence with a 40-micrometre diamond followed by a 15-micrometre diamond produced low Ra values and superior quality margins. Grundy (1985), studying effects of abrasive agents on a hybrid posterior composite resin (16), found that diamond burs "even the finest currently available" tear filler
particles from the composite.

Chen, Chan and Chan (1988), in their study of finishing and polishing techniques on a microfilled composite (17), also did not find 40-micrometre and 15-micrometre diamond burs (18) satisfactory. However, if the diamonds were followed by a Vivadent polishing point (rubber impregnated with silicon dioxide) (19), the result - as measured by the relative reflectance value and by the presence of grooves and scratches - was not significantly different from that achieved by disks (20). Unfortunately, this result was not repeated by Tjan and Chan (1989) who found that the Sof-Lex disk system (20) produced, with one exception (21), significantly smoother surfaces - as measured by Ra values - than those produced with the Vivadent polishing system (22). This was true for microfilled, hybrid and conventional composite resins, although the differences were smaller with the microfilled and small particle hybrid composite resins.

Lutz, Setcos and Phillips (1983) considered the use of high speed for finishing diamond burs "absolutely contraindicated" and recommended that they be operated at 5,000 to 15,000 rpm, under a "generous water spray". Grundy (1985), on the other hand, used the diamonds in a turbine handpiece, while all the other abrasive agents, apart from a "tungsten stone", were used in a low speed handpiece at 6,000 to 8,000 rpm, and all agents were applied wet. Boghosian, Randolph and Jekkals (1987) operated their diamond instruments at low speed (30,000rpm) and the tungsten carbide burs at high speeds (free-spinning speed 375,000rpm), all under continuous air-water spray. Eide and Tveit (1988) used polishing disks dry, and all the other agents wet, at speeds 12,000 to 24,000
rpm, except for the polishing paste, which was applied at 6,000 rpm. Pratten and Johnson (1988) operated their diamond instruments at both high (400,000 rpm) and low speed (20,000 rpm) – both with continuous water spray – and found that, in general, less roughness was produced at low speed. While it is obvious that there is a lack of uniformity, it does appear that although high speeds have been used with diamonds, low speeds may be used and possibly with superior results, and that with the exception of the polishing disks and Vivadent polishers (Chen, Chan and Chan, 1988), water spray is used.

What can be achieved by the use of polishing paste is somewhat uncertain. Tjan and Chan (1989) found that no reduction in surface roughness was obtained by additional polishing with 0.3-micrometre alumina paste (23). Horton, Paulus, Pelleu, and Rudolph (1977), studying the effect of polishing pastes (24, 25, 26) on a conventional composite resin (27), found that each of the pastes increased the roughness significantly. Reinhardt, Denehy, Chan, Rittman, Heitkamp and Smith (1983) found that the use of an alumina polishing paste (25) after Sof-Lex disks generally improved the surface of hybrid and microfilled composite resins. Pratten and Johnson (1988) also found that when the Sof-Lex disks' sequence was followed by a polishing paste (28), the Ra of the two hybrid composite resins (14, 15) was reduced. However, the difference was not significant. Eide and Tveit (1988), studying different methods of finishing and polishing on a microfilled composite resin (Silux) and a hybrid composite resin (P30), did not find any effect achieved by a polishing paste (29). They applied the paste for only 10 seconds and commented that a longer application might have been more
beneficial. However, Tjan and Chan (1989) applied the paste for 60 seconds with no reduction in surface roughness of microfilled, hybrid and conventional composite resin.

While, as mentioned earlier, a highly polished surface is desirable, particularly in the gingival areas, the labial surface may be overpolished, creating a "plasticky" appearance (Bryant, 1989). This can be generally avoided by omitting, where required, the last disk of the sequence in this area. Sometimes more macroscopic irregularities may have been removed by polishing. This may be addressed by roughening the polished surface with a slowly rotating coarse diamond and then repolishing it with the superfine disk (Croll, 1988).

Clinical recommendations. Before rotary finishing instruments are used, the margins of the composite resin crown should be sealed with unfilled resin. Glossy surfaces of very low roughness may be achieved with the use of aluminium oxide polishing disks in sequence. Adequate proximal surfaces may be achieved with the use of aluminium oxide strips in sequence. On concave surfaces and at the gingival margins, tungsten carbide burs (12-blade burs followed by 30-blade burs) or diamonds (40-micrometre grit followed by 15-micrometre grit), followed by polishers of rubber impregnated with silicone dioxide, may be used. There is some evidence that diamonds are more suitable for microfilled composite resins, and tungsten carbide burs for hybrid composite resins. It is uncertain whether the use of polishing pastes is beneficial. The finishing and polishing instruments should be used in a low speed handpiece. The diamonds and tungsten carbide burs should be used with water spray.
PRODUCTS:

(1) Concise Enamel Bond. 3M Co., St. Paul, Minn., USA.
(2) Tubulitec. Dental Therapeutics AB, Nacka, Sweden.
(3) Sof-Lex polishing disks. 3M Co., St. Paul, Minn., USA.

(6) P30. 3M Company, Minn., USA.
(9) White stone. Shofu Dental Corp., Menlo Park, Calif., USA.
(10) Command Ultrafine. Kerr/Sybron Corp.
(11) Midwest carbide (7406) 12-fluted. Midwest/Sybron, Des Plaines, Ill., USA.
(12) Brasseler ET carbide (CSI). Brasseler USA, Inc., Savannah, Ga., USA.
(13) Brasseler ET diamond, x-fine (15 micrometres). Brasseler USA, Inc., Savannah, Ga., USA.
(14) Bisfil-I. Bisco Inc., Lombard, Ill., USA.
(15) Bisfil-M. Bisco Inc., Lombard, Ill., USA.
(17) Silux. 3M Co., Dental Products Div., St. Paul, Minn., USA.
(18) Densco diamond burs. Teledyne Densco, Denver, Colo., USA.
(19) Vivadent polishing point. Vivadent USA, Inc., New York,
NY, USA.

(20) Sof-Lex. 3M Co., Dental Products Div., St. Paul, Minn., USA.

(21) Herculite. Sybron/Kerr, Romulus, Mich., USA.

(22) SiO₂ impregnated rubber polisher. Vivadent, Buffalo, NY, USA.

(23) Luster paste. Sybron/Kerr, Romulus, Mich., USA.

(24) 3M composite polishing paste. 3M Co., St. Paul, Minn., USA.

(25) Precise polishing paste. Lee Pharmaceuticals, South El Monte, Calif., USA.


(27) Concise. 3M Co., St. Paul, Minn., USA.


2.5 CONCLUSIONS

1. The direct composite resin crown is an appropriate mode of treatment, which fulfills the requirements of a successful crown and benefits the patient when used in indicated cases.

2. Further studies to examine the long-term survival of composite resin crowns are necessary.

3. New materials are constantly appearing on the market and new techniques are constantly being developed. They are likely to increase the longevity of composite resin crowns and widen their indications. However, it should be kept in mind that there will always be a lag between the appearance of a new material or the development of a new technique and the time they can be considered clinically proven.
BIBLIOGRAPHY


Bass E. Personal communication. 1990.


Brauer GM. Color changes of composites on exposure to various energy sources. Dent Mater 1988;4:55-9


Clinical research associates. Liners/bases, glass ionomer, light cured.


Falian H, Dexin Z, Weizhong J, Guangming Z. Bonding of resinuous filling


Guzy GE, Nicholls JI. In vitro comparison of intact endodontically


Henry PJ. Photoelastic analysis of post core restorations. Aust Dent J


Mizrahi E, Smith DC. Direct cementation of orthodontic brackets to


Mount GJ. The wettability of bonding resins used in the composite resin/glass ionomer 'sandwich technique'. Aust Dent J 1989a;34:32-5.

Mount GJ. The tensile strength of the union between various glass ionomer cements and various composite resins. Aust Dent J 1989b;136-46.


Peyton FA, Craig RG, eds. Restorative dental materials. St. Louis: Mosby,


Provenza DV, Seibel W. Oral histology. Inheritance and development. 2nd


Tyas MJ. Update in restorative materials. Lecture presented at a seminar organised by Postgraduate committee in dental science in Sydney.
1989.


Ultradent Products, Inc. Pre-comp system, individual components, instructions. SLC, Utah, USA. 1982:8.


