CHAPTER 8.

ACRYLIC AND COMPOSITE RESIN VENEERS.

Advances in the treatment of discoloured teeth are largely attributable to a remarkable improvement in materials, particularly composite resins. The materials currently available, combined with the now familiar acid-etch technique have provided immense benefits through their application as luting agents, restorative and veneering materials. In the late 1940's, self-curing unfilled acrylic materials were introduced, in which the polymer and monomer could be combined and inserted into a cavity whilst still in a plastic state, where it then polymerised. These early resins possessed poor physical properties by today's standards, particularly regarding colour stability as they darkened upon exposure to sunlight due to their amine content. In addition, they exhibited poor abrasion resistance, low modulus of elasticity, high amount of water absorption, poor compressive strength and high polymerisation shrinkage of approximately 7 per cent by volume. Their high coefficient of thermal expansion created the potential for marginal leakage and therefore, recurrent caries was a major shortcoming (Roulet, 1987).
8.1 Composite Resin Materials Science.

Dental resins are composed of polymers which may be defined as being a very large molecule formed by joining many small molecules, or monomers. Acrylic polymers were first introduced into dentistry in 1937 primarily for use as denture bases, after which their popularity grew to the point where by 1946, 98 per cent of all dentures were constructed of this material. The simplest form of acrylic is the polymer derived from methylmethacrylate (MMA) and is therefore known as poly(methylmethacrylate), or PMMA. The formulae are shown in Figure 8.1.

Polymer molecules may be prepared from different monomers. If they contain two or more different monomers they are "copolymers" and if three or more are present, "terpolymers". Copolymers which are capable of linking two polymer chains are known as cross-linking agents. Cross-linking improves the physical and mechanical properties of the polymer by restricting the molecular movement of the single polymer chains (Craig, 1985; Roulet, 1987).

One of the major shortcomings of acrylic is its polymerisation shrinkage. This was found to be due to the change in interatomic distances before and after polymerisation. Before this process, the monomer
Fig. 8.1. Formulae of MMA and PMMA.
molecules are separated by a distance of 0.4 nm, whereas after polymerisation, the molecules are separated by their atomic bond distance, which is approximately 0.2 nm for covalent bonds, representing a difference of 0.2 nm. Consequently, for each new bond there is a cylindrical volume loss. Given that the volume \( (v) \) of a cylinder is determined by the formula \( v = \pi r^2 h \), and that \( h \) equals the lost distance, in this case 0.2 nm, the lost volume is equal to the radius of the atom squared, multiplied by 0.2 nm \( \times \pi \). Roulet (1987) stated that this phenomenon results on a polymerisation shrinkage of 21 per cent by volume during the polymerisation of MMA to PMMA. As a result, before such a material could be used for precise dental work, the problem of shrinkage needed to be overcome. This may be achieved by adding inert fillers to form a composite material, or by using prepolymerised particles. In the latter method, prepolymerised spheres of MMA become entrapped into the newly polymerised PMMA matrix, resulting in a reduction of shrinkage by about one half. In addition, larger monomer molecules may be used in order to ensure that the volume change due to the polymerisation process is a lower percentage of the overall volume.

Polymerisation shrinkage still exists in modern materials as demonstrated by Walls et al (1988). These authors even found differing degrees of contraction between commercially available brands and shades of
the same type of material. It was shown that the magnitude of contraction is influenced by filler loading and is related to the heat generated during the exothermic polymerisation reaction. The darker shades underwent lower contraction than lighter shades which may be attributed to a reduced quality of cure within the darker material.

It was the quest for larger molecules that led Bowen (1958) to discover that the reaction between bisphenol A and glycidylmethacrylate thinned with triethylene glycol dimethacrylate cured within three minutes at room temperature by forming a resin, commonly known as Bis-GMA (Fig. 8.2). This resin material formed the basis for composite resin restorative materials, which became the natural progression from PMMA resins for anterior use. By definition, a composite material refers to a three-dimensional combination of at least two chemically different compounds with a distinct interface separating the components (Phillips, 1987). If executed correctly, such a combination should provide properties superior to those of the components acting separately. Therefore, a composite resin is one in which a maximum amount inorganic filler has been added to a minimum amount of binder, which is composed of a cross-linking polymerisable organic resin. In comparison to PMMA resins, composite resins possess much improved physical properties by means of an improved resin matrix and high percentage of inorganic filler.
Fig. 8.2. The production of Bis-GMA.
Modern composite resins consist of four phases:
1. the resin matrix,
2. dispersed or reinforcing phase (fillers),
3. the interface between the dispersed and matrix phases (coupling agent),
4. other constituents (viscosity controllers, inhibitors, thermochemical or photochemical initiators, accelerators, colourants).

The resin matrix phase is most commonly composed of Bis-GMA, or its chemical name: 2,2-bis-[4(2-hydroxy-3-methacryloyloxy-propyloxy)-phenyl]-propane, which is a high viscosity oligimer usually not suitable for use alone as a dental restorative material. Consequently, monomeric compounds are added which lower the viscosity to improve handling properties and the ability to include filler particles during manufacture. The monomers used for this purpose may be monofunctional such as methylmethacrylate, or difunctional; the latter being preferred by most manufacturers. Difunctional monomers offer the advantages of undergoing less polymerisation shrinkage, providing a higher degree of cross-linking, which results in a harder and stronger material with a lower coefficient of thermal expansion. In addition, they are less volatile and form polymers which possess a lower water sorption capacity. The most commonly used diluent monomers are ethylene glycol dimethacrylate
(EGDMA) and triethylene glycol dimethacrylate (TEGDMA), although most manufacturers use blends of these and other monomers in order to achieve different properties. However, these materials greatly affect the mechanical and physical properties of the resulting composite. Most increase the polymerisation shrinkage, but some monomers such as polyfunctional methacrylates improve mechanical properties and others may improve marginal adaptation. Therefore, the constituents and their amounts greatly influence the properties of the final materials and as such, are not disclosed by the manufacturers (Craig, 1981; Phillips, 1982; Craig, 1985; Combe, 1986; Roulet, 1987).

Although Bis-GMA or Bowen's resin has remained in use since its inception, it has several disadvantages. These include the need for diluents, air inhibition of polymerisation, and high water sorption. Thus, extensive research has been undertaken to find an alternative resin matrix. However, there is little evidence in the literature to suggest that a suitable replacement is imminent. Until such a replacement is found, Bis-GMA remains the most common resin. Despite this, other resins such as urethane dimethacrylates have been employed, although the properties of composites based upon these monomers are generally similar to those containing Bis-GMA (Combe, 1986).

The reinforcing phase refers to the inorganic filler content of a composite restorative material,
first introduced by Bowen (1958). The concentration of the filler in a composite must be high if deformation of the matrix is to be avoided. In addition, the filler also reduces the coefficient of thermal expansion of the resin matrix. Consequently, a higher ratio between the dimensionally stable filler and the dimensionally unstable resin will result in a lower coefficient of thermal expansion.

Essentially, the filler component of composite resins should exhibit a high degree of hardness, be chemically and biologically inert, possess low thermal expansion and have a refractive index and translucency which approaches that of natural tooth structure. Several types of inorganic materials have been used for this purpose such as fused silica, crystalline quartz, lithium aluminium silicate, barium and strontium borosilicate glasses, and barium aluminium silicate. The fillers have been used in numerous forms such as spheres, splinters or ground powders, the latter of which is best retained in the matrix (Martin, 1980). Different fillers impart various properties into the material. For example, barium or strontium glass fillers produce radiopacity, and strontium glasses are claimed to be softer and therefore more polishable (Combe, 1986).

The incorporation of inorganic particles into resins is a complex process. They are produced by
grinding and milling, precipitation, or by condensation. Grinding and milling produces particles ranging between 0.2 and 100μm, and precipitation techniques result in particles from 0.02 to 0.4μm. In addition to particle size, their shape, size distribution, surface area, chemical composition, optical properties, radio-opacity and filler load all greatly influence the behaviour of the composite material, and are interrelated. Therefore, optimising one parameter may compromise others.

Maximum filler load is determined by particle size distribution, particle shape and surface characteristics. Using a uniform particle size would not lead to a high filler load since there is a higher void percentage (Fig. 8.3 a). However, a range of particle sizes may result in higher filler loads since the void between the particles is reduced. Therefore, to achieve a high degree of packing, the geometric progression depends upon the final voids left in the system after the smallest particles are included and upon a very wide range of particle sizes (Fig. 8.3 b).

The inorganic filler content, usually expressed as a percentage by weight, greatly influences the clinical performance, particularly in stress bearing areas. Because the particle size and filler content are interrelated, these parameters have given rise to the four present categories of visible light cured composite materials which are seen in Table 8.1.
<table>
<thead>
<tr>
<th>LARGE-PARTICLE</th>
<th>SMALL-PARTICLE</th>
<th>HYBRID</th>
<th>MICROFILLED</th>
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Table 8.1. Average particle size of the four categories of composite resins.
Fig. 8.3. Degree of filler loading possible with:
A) one particle size,
B) two or more particle sizes.
Microfilled composites are a recent development introduced in response to demands for a more polishable and colour stable material. The inorganic filler in most of these materials is colloidal silica, which has a mean particle size of 0.04μm. Particles of this size possess a very large surface area (approximately 300m²/g) and upon incorporation rapidly increase the viscosity of the base resin. Although the viscosity of the base resin, particularly Bis-GMA, may be decreased by the addition of low molecular weight diluents, the final composite usually contains only around 30-50 per cent by weight filler if a clinically usable viscosity is to be maintained. (Craig, 1985). This problem is overcome to a large extent by polymerising the resin containing the colloidal silica and then grinding the set material into irregular particles between 10 and 50μm. These prepolymerised particles are then incorporated into an unpolymerised resin base and further filler added which will result in the final resin with a filler content of 40-55 per cent by weight. Filler content of microfilled composites can be further enhanced by the use of microfiller-based complexes of which there are three types: splintered prepolymerised microfilled complexes (SPP), spherical polymer-based microfilled complexes (SphPB), and agglomerated microfiller complexes (AMC). SPP's are made by grinding a heat cured mixture containing silica and its resinous matrix, producing particles in
a range of 1-200μm. These particles are often incorrectly referred to as "organic fillers" and are in essence, "filled fillers". SphPB's are produced in a similar fashion, but instead of grinding, spherical particles are formed with suspension polymerisation, to a size of 20-30μm. AMC's consist of primary particles ranging between 0.001-0.1μm which, following a heat treatment agglomerates the particles to produce secondary particles ranging from 0.5-50μm in size (Roulet, 1987).

Despite the increase in filler content achieved by the use of prepolymerised particles, it is still below that of other materials. Macrofilled composite resins consist of fillers that measure 1-5μm in diameter, which due to the larger size comprise 70-80 per cent by weight. Composite resins which contain fillers in this size range are known as "small particle macrofilled" materials, whereas those containing particles greater than 10μm are known as "large particle macrofilled" systems. Relative to microfilled composites, these materials do not polish well, and are more difficult to contour and finish. These shortcomings may be attributed to the large particles and the difference between the hardness of the filler and resin. Since the fillers used are much larger than the wavelength of visible light (0.385-0.760μm) they are easily detectable. Clinically, the matrix may be removed, the interfacial phase
may be hydrolysed or filler particles "plucked" out, which contribute to rough and dull surfaces, poor wear properties, enhanced plaque adhesion and increased tendency to stain. The advantage of the larger particles is the significant increase in strength imparted by means of the greater filler loading, which may be between 75 and 80 per cent by weight.

The difference in clinical performance between macrofilled and microfilled composites has been compensated for by the development of hybrid materials. To meet the needs of both improved polishability and increased strength, they contain microparticles (0.04μm) and macroparticles (1-10μm) thus enabling a filler content within a range of 70-85 per cent by weight. Depending upon the size of the macroparticles, which varies between manufacturers, different properties, particularly polishability and finish can be exhibited. In addition, some types of fillers such as strontium glasses are soft enough to be polished themselves, which negates the usual polishing problems, namely the loss of surface particles and exposure of base resin. The more recent hybrids contain fillers with an average size of 0.8-1.0μm, which means that even if the larger particles are exposed or plucked during use, only slight decreases in surface gloss may be anticipated (Jordan, 1986; Roulet, 1987; Valentine, 1987).
The third phase is the interface between the dispersed and matrix phases, or the coupling agent. In order for reinforcement of the polymer by the filler to occur, thereby transferring stress under load from the high strength filler to the resin matrix, the two should be bonded together (Craig, 1981; Combe, 1986). This is achieved by the use of a coupling agent which is attached to the inorganic reinforcing phase and reacts with the organic phase. The coupling mechanism involves hydrolysis of the methoxy groups with either surface water bound to the filler, or with silanol or aluminol groups of the filler. The carbon double bonds are then available for polymerisation with the matrix during the setting of the composite. The most common coupling agents are silanes such as vinyl triethoxy-silane and 6-methacryloxypropyltrimethoxysilane (Fig. 8.4.) (Craig, 1981; Combe, 1986; Roulet, 1987).

The final phase existing in dental composite resins arises from the remaining components which render the material suitable for clinical use. The addition of viscosity controllers or diluents which have been discussed previously, is responsible for maintaining a workable consistency.

To prevent premature polymerisation, inhibitors are incorporated to ensure adequate shelf life of dental composites. Compounds which inhibit polymerisation of diacrylates include 4-methoxyphenol and 2,4,6-tri-tertiarybutyl phenol. They are only used in amounts of 0.1 per cent or less.
Fig. 8.4. Formulae of commonly used silanes.

Q = hydrolysable group of silicone

R = organofunctional group compatible with the base resin.
Once the composite resin restoration has been placed, polymerisation must be initiated. Early composites included thermochemical initiators which required a two-paste system, which when mixed and inserted into the cavity, set of their own accord. These resins are not relevant when dealing with direct composite resin restoration of a discoloured tooth, but are included in the dual-cure composite luting agents used with indirect laminate veneer restorations. Most modern composite resins use a photochemical initiator, which prevent premature polymerisation until electromagnetic radiation of a specific wavelength initiates polymerisation. Initially, ultra-violet light was used for this purpose. However, the more recent composite resin systems utilise a visible light source within the range 460-485nm in wavelength. Regardless of which system is used, the reaction must be initiated by generating free radicals, thereby opening up the unsaturated carbon bonds in the methacrylate groups to provide a receptor site for bonding with other activated groups which form polymers. Substances containing diketones are used for the production of free radicals since they absorb light energy in the blue range. Examples of photosensitive initiators are benzyl, biacetyl and acenaphthene quinone and camphoroquinone. Self-curing systems utilise benzoyl peroxide as an initiator to generate free radicals which initiate polymerisation (Bowen, 1979). In
addition, reducing agents such as tertiary amines and alkanol amines are included to decrease the required curing time.

The close clinical colour matching of composite resins to natural tooth structure renders such materials suitable for anterior use. They are available in a variety of shades, which are produced by the addition of appropriate amounts of inorganic pigments. Composites can then be mixed, allowing an almost limitless number of shade possibilities. The optical properties and colour stability will be discussed later in this chapter.

The use of composite resins in the treatment of discoloured anterior teeth is usually confined to either partial or full labial coverage, which may or may not include the incisal edge of the tooth. Consequently, from a primarily aesthetic viewpoint, the finish, colour matching, stability and optical properties are most important. In addition, the strength of the material under functional load is of vital importance in order to prevent fracture if, for example, the incisal edge is to be included. The remaining properties of composite resins have been well documented and are beyond the scope of this review.

As mentioned previously, particle size and filler content are interrelated, and are the parameters most
responsible for the strength of a particular composite resin. Given that aesthetics and polishability are of primary importance, the appropriate materials are microfilled, hybrid and to a lesser extent, small particle macrofilled composites. It is universally accepted that microfilled resins are the most prone to fracture in high-stress situations, yet they produce the highest polish. The compromise achieved by the introduction of hybrids has meant that a material with significantly improved mechanical properties may be used in aesthetic situations with an acceptable degree of polishability. Small particle macrofilled materials are in a similar category, but are more prone to losing the lustre produced during finishing due to surface degradation which occurs in time (Badenhorst and deWet, 1987).

Probably the most important consideration in determining which material should be used is the patient's occlusion. During the pre-operative examination, signs and symptoms such as bruxofacets, ledges on the lingual surface of maxillary anterior teeth, fractured or cracked teeth, temporomandibular joint pain and associated symptoms should be assessed. If any of these indications are present, serious consideration should be made regarding the extent and use of composite resins, unless other forms of therapy are indicated to precede such treatment. If occlusal problems exist, splint therapy, orthodontic or
surgical correction may be advisable prior to composite resin treatment. In addition to physiological problems, the practitioner must identify destructive habits such as nail biting, pencil chewing and the eating of hard foods. In either case, the final restoration should be finished such that it undergoes no interferences in any functional movements. This is especially pertinent to microfilled resins (Christensen, 1985; Weinstein, 1988).

Periodontal considerations also play a part in the final decision as to which type of material should be used. Before treatment commences patients must be made fully aware of the requirements of home care and thorough oral hygiene. Active periodontal disease and inflammation must be controlled before treatment. Once this is under control, either hybrids or microfilled materials can be used. However, if there is doubt, microfilled resins are first choice due to their superior polishability which reduces the tendency for plaque adherence. If a patient loses oral hygiene motivation following treatment with a hybrid material, plaque accumulation may occur and lead to gingival inflammation and/or recurrent caries. If it is foreseen that plaque adhesion may be a problem, alternative forms of treatment such as full or partial coverage utilising porcelain, which is significantly
less susceptible to plaque adhesion, may be contemplated (Wunderlich and Caffesse, 1985). However, the extent of plaque accumulation is often dependent upon the skill of the operator in obtaining a satisfactory finish, and in many circumstances is quite independent of the material used. deWet and Ferreira (1982) found that microfilled resins may be finished to a high gloss such that little or no plaque adheres to the surface. Consequently, these authors recommended microfilled materials as being suitable for areas adjacent to or slightly below the gingival level.

Dental restorative materials should have similar optical properties to tooth structure if they are to play a role in enhancing or maintaining proper aesthetics. That is, their colour and translucency should match those of enamel and dentine wherever possible. The physics of this concept may be partly explained by Fresnell's equation,

\[ R = \frac{(N_1 - N_2)^2}{(N_1 + N_2)^2} \]

where \( R \) is the relative amount of reflected light, \( N_1 \) the refractive index of the particle and \( N_2 \) is the refractive index of the surrounding medium. This equation suggests the translucency of a composite is enhanced if the refractive index of the filler matches
or approaches that of the resin. Roulet (1987) stated that diacrylates used in composites have refractive indices of approximately 1.5. Therefore, the choice of fillers is restricted to those materials with similar indices, if aesthetic requirements are to be fulfilled. Quartz and most glass fillers possess refractive indices of about 1.5.

The translucency and colour of a composite resin may be characterised by the absorption coefficient $K$, and the scattering coefficient $S$. These parameters which are wavelength-dependent, have been calculated in several studies, based on the Kubelka-Munk equations (Grajower et al., 1982; Yeh, Migawa and Powers 1982; Powers et al., 1978; Cook and McAree, 1985). The resulting calculations were based on reflectance spectra of samples of various thicknesses when placed on black, then white backgrounds. Grajower et al. (1982) found that the colour of the sample of composite resin of a specific thickness when placed on a particular background may be accurately predicted from calculations employing the $K$ and $S$ values of the resin and the reflectance spectra of the background material. From similar studies, Cook and McAree (1985) and Yeh, Powers and Migawa (1982) stated that the prediction of reflective spectra and colour for different specimen thicknesses and backgrounds should provide manufacturers with an aid in selecting toothlike shades. This is particularly appropriate if materials are chosen which have $K$ and $S$ values similar
to enamel and dentine. However, the variables of the influence of underlying pulp tissue and opaque masking agents if used, are not considered by this theory and therefore require further attention. Despite this, Cook and McAree (1985) concluded that contrary to other studies by Dennison et al (1978) and Jorgenson and Goodkind (1979), who suggested that several materials contain shades outside the natural range, most restorative materials are generally consistent with natural tooth sections. This conflict can be attributed to the rapid progress in the field of composites within the period of the late 1970's and mid 1980's. However, Cook and McAree (1985) stated that although composite resins mainly fall into the natural ranges of hue, value, and chroma, there is a considerable difference in their reflectance spectra compared with those of natural teeth which suggests that many of these materials will be highly metameric with the natural dentition when viewed under different lighting conditions. Viohl (1981) stated that the factors influencing the estimation of colour match are as follows:

1. illuminance,
2. quality of light,
3. uniformity of illumination,
4. location of the restoration's margin,
5. reflection from the surface,
6. normal colour vision.
In addition to those variables, it should be noted that an individual's opinion of a colour match may change, despite vision problems such as colour blindness which may contribute to uncertainty. That is, a person may select different shades on different occasions or various people may select different shades for the same case.

Since their inception, composites have been prone to a marked degree of colour instability. Stain accumulation, dehydration, water sorption, and the chemical breakdown of unreacted components all contribute to colour change (Powers et al, 1978). However, the more recent light cured systems do not undergo such marked colour change in time. This can be attributed to several factors. Firstly, light cured materials do not require polymerisation accelerators such as tertiary aromatic amines used in chemically cured composites. These amines may undergo chemical change in the oral environment causing colour change seen clinically as a yellowing or darkening of the restoration (Jordan, 1986; Roulet, 1987). In addition, several materials possess compounds which absorb electromagnetic energy just below the blue region of the spectrum thereby adding a degree of protection from ultraviolet radiation. An example of such a compound is 2-hydroxy-4-methoxybenzophenone (Bowen, 1979; Combe, 1986).
The third major reason why modern composite resins show improved colour stability is their higher degree of polishability which reduces the tendency of these materials to allow plaque adhesion and stain uptake. This is especially relevant to microfilled and hybrid materials. However, these materials are also subject to colour change under certain conditions. Incomplete curing may lead to a blanching or lightening of the restoration as it ages as a result of bleaching of the photoinitiator, and cause water sorption whereby unreacted components may leach out of the composite mass (Phillips, 1987). In addition, porous or rough surfaces which may be caused by the incorporation of air during the mixture of shades or by inadequate finishing procedures, may cause plaque adhesion and the uptake of stains from tobacco smoking, tea, coffee, and other food products (Reinhardt et al, 1983).

Colour stability of microfilled resins has been the subject of many studies since their inception. Ameye et al (1981) found by visual examination that microfilled materials had greatly improved stability in this area. Ruyter et al (1987) used spectro-photometric analysis to examine composite resins following accelerated aging, and found that there were measurable differences, indicating the potential for the material to degenerate over a period of time. Similarly, Brauer (1988) found that under experimental
conditions simulating the aging process with ultra-violet light, discoloration of composites increases with exposure time. This author also found that lighter shades are more susceptible to colour change than darker shades made by the same manufacturer. However, colour comparisons used in tests of this nature are not truly indicative of the clinical performance, since they only disclose the propensity of the material to undergo colour change. Clinical studies are also difficult in this area due to the rapid changes which are presently occurring. That is, a study of materials available in, for example, 1980 utilising chemically cured and early light cured materials is of little benefit, since such materials are seldom used today. Clinical evaluation is also made difficult by the lack of definite characteristics. Because colour is such a subjective phenomenon, the best evaluation mechanism is a well trained observer. There are no instruments for determining the colour of curved and partially hidden and shadowed restorations. Therefore minor variations in colour are often hidden from the patient by inconsistent illumination and reflection (Viohl, 1981).

It has been widely accepted that resin materials are subject to staining in certain media (Cooley and Barkmeier, 1988). Susceptibility to staining is linked to many factors, including water sorption, porosity
and finish. These can be countered by incorporating a hydrophobic resin matrix system, avoiding the inclusion of air during mixing or placement, and by proper polishing techniques. Polishing refers to the removal of macroscopic scratches produced by gross finishing instruments, thereby resulting in a smooth surface or high gloss, depending on whether a hybrid or microfilled material is used (Weinstein, 1988). Reinhardt et al (1983) found that from SEM data, the best polishing method varied with each material used, but clinically, polishing discs produced the most satisfactory results.

Other methods of polishing include fine-grit proximal strips, abrasive impregnated rubber points and wheels, and polishing pastes. Weinstein (1988) suggested that microfilled resins polish best with discs or abrasive rubber instruments whereas hybrids are best polished with 30-fluted carbide burs followed by polishing pastes. For best results, the abrasive in the polishing materials should be finer than the particle size of the composite resin used.

Regardless of the type of composite to be used, the technique used to retain the material is essentially the same. This technique, introduced by Buonocore in 1955, utilises an acid solution which etches the enamel prisms in order to create micro-porosities which allow resin tags to penetrate and
produce a mechanical interlocking relationship. The acid which Buonocore recommended, and which has remained in use is phosphoric acid, in a concentration of between 30 and 50 per cent. The lower the concentration, the deeper is the resultant etching and conversely, a concentration of around 50 per cent may cause a monocalcium phosphate monohydrate to form on the enamel which prevents further dissolution (Phillips, 1982). Thus, the concentration of phosphoric acid most commonly used is approximately 35-37 per cent.

The etching time itself has been somewhat of a contentious issue in the past, complicated further by factors which affect the vulnerability of the enamel to the acid solution. Much research has been carried out regarding etching time. Rather than concentrating on providing a quantitative answer, Williams and von Fraunhofer (1977) concluded that varying the etch and wash time affected the bond strength and recommended the most clinically satisfactory combination of etch and wash time was that suggested by the manufacturer. Nordenvall et al (1980) compared the effects of 15 and 60 seconds of etching with a 37 per cent phosphoric acid solution on enamel surfaces of young and old permanent teeth. Using the SEM, they found that for young permanent teeth, 15 seconds of etching created more retentive conditions than 60 seconds. The reverse was found for older teeth. In contrast to this
finding, Shay et al (1988) observed no significant variation between age and enamel calcium solubility.

For several years the nominal etching time has been around one minute. However, several recent reports have indicated that a reduced time will still provide the same etching patterns thereby decreasing enamel loss and saving chair time without affecting clinical performance (Barkmeier et al, 1985; 1987). Baharav et al (1987) advocated the application of the etchant with a continuous brushing technique, since this action is said to enhance decalcification of enamel by ensuring proper wetting of the enamel by the etchant. In addition, a more debris-free surface is claimed to occur. However, this finding has been questioned by Shay et al (1988).

The recommended etching time has been reduced on the basis of the studies referred to above from 60 to 30 seconds. However, this may vary depending upon individual factors. It may be increased if the patient is older, due to the long-term uptake of fluoride from food and water, and other minerals which may reduce the potential of the enamel to dissolve. In addition, Gwinnett (1967) stated that the existence of "prismless" enamel, which occurs most frequently (70 per cent incidence) in the cervical region of permanent teeth, exhibits a scale-like crystalline arrangement which is unlike "normal" enamel. As a result, a history of exposure to fluoridated water,
and the presence of "prismless" enamel both require longer etching time. Similarly, preparation of the surface usually results in the production of a smear layer which may prevent penetration of the acid solution to the point where adequate bonding is unlikely if etched for only a short time. Adequate etching may be judged by the well known macroscopic appearance of white, chalky enamel, and if this is not the case, the enamel should be re-etched for 15 seconds. This is evident following thorough washing and drying with compressed air. The enamel surface should not be scrubbed or rubbed as this may damage the enamel lattice work (Valentine, 1987).

The role of washing after etching cannot be over-emphasised. This procedure rinses away any debris which may prevent the formation of resin tags. Phillips (1982) stated that a stronger resin-enamel bond occurs after a longer washing time, which Phillips recommended should be at least 45 seconds. Similarly, thorough drying with uncontaminated compressed air is necessary to allow the bonding resin to flow into the microporosity and provide retention. The etching procedure raises the surface energy of the enamel which increases its wettability, and hence provides better saturation of the enamel by the bonding agent. Further contamination by saliva or tissue fluids lowers the surface energy, thereby weakening the resin-enamel bond. Consequently,
contamination between etching and the application of resin must be avoided. Given that the treatment of tooth discoloration usually requires labial coverage with no traditional means of retention such as mechanical undercuts, the etching procedure must be stringently carried out if the restoration is to remain bonded to the tooth.

Occasionally, a tooth may be devoid of enamel in areas which require coverage with a composite. This usually occurs in the cervical region, most often due to gingival recession, abrasion or erosion. In addition, if tooth preparation is required to make room for a composite veneer, penetration of enamel into dentine is possible, particularly in the area of thinnest enamel in the cervical area. Although dentine may be etched, the etching patterns produced are not conducive to retention which may lead to problems arising from lack of retention and the possibility of microleakage. In such a situation, the use of glass ionomer materials or dentine bonding agents (DBA) are required. This area of adhesive dentistry, particularly concerning DBA's is still in its relative infancy, and a full discussion of these materials is beyond the scope of this review.

The modern labial veneer restoration has evolved from a combination of the acid-etch procedure developed by Buonocore in 1955, the refinement of
Bis-GMA resin by Bowen in 1962 and the introduction of light-cured microfilled composite resin in 1979. These significant achievements have produced a procedure now almost universally recognised and utilised. As mentioned previously, these restorations cover the visible labial surfaces of affected teeth, and may or may not include the incisal edge, depending upon occlusal factors. Labial veneers may be classified as follows (Black, 1985):

1. direct bonded or freehand composite veneers.
2. preformed acrylic or composite veneers,
3. customised indirect laboratory fabricated resin and porcelain veneers.
8.2 Direct Composite Resin Veneers.

The first consideration in formulating a treatment plan is the caries incidence and condition of the periodontium. Patients must be made aware of the need to maintain an effective preventive programme, and progress in this area should be monitored by the practitioner. Signs of incorrect brushing techniques such as cervical abrasion should be observed, and plaque disclosing methods utilised before necessary modifications to brushing are made. Pocket depth, loss of attachment, gingival recession, and mobility should also be noted. Thorough periodontal examination should evaluate the need for crown lengthening procedures, alveolar surgery and any other pertinent techniques which render the dentition suitable for treatment of this nature. Patients with sound periodontal health and a low caries incidence are more likely to respond well to labial veneer restorations.

The second consideration is the patient's occlusion. Signs of bruxism, traumatic occlusion and habits which may be relevant should be evaluated. This area is very closely related to the previous discussion concerning the selection of an appropriate composite material. Treatment planning should also encompass other aesthetic factors such as the shape of the face, the patient's age, and gender, all of which
contribute to incisal and facial embrasure form. In addition, minor orthodontic problems which do not contribute to occlusion may be corrected by the placement of resin in appropriate areas which re-establishes a harmonious arch form (Weinstein, 1988).

Irrespective of the veneering technique to be used, the question of tooth preparation prior to acid-etching has been controversial. One opinion is that the process should be reversible and therefore warrant no mechanical preparation of the enamel surface (Mink and Timmons, 1984). Christensen (1985) stated that unless teeth are labially inclined, removal of the enamel is not required or desirable. In addition, he stated that an increase in the facial thickness of the veneered teeth by 0.5-1.0mm is not objectionable in most cases and is in fact less than the amount added labiolingually by most metal-ceramic crowns. This opinion is consistent with most authors before the mid-1980's, who either stated that no tooth preparation was necessary, or made no mention of it at all, thereby inferring that such a step was not required. However, most recent opinions, and occasionally those before the mid-1980's, revolve around the necessity for some tooth preparation to be carried out. Black (1982, 1985) and Harding (1984) stated their preference towards enamel reduction, and this
has been supported more recently by Heymann (1987), Valentine (1987), Weinstein (1988), and Garber et al (1988). The majority of authors favour the uniform reduction of enamel of 0.5mm, with a definite chamfer margin to provide finish lines at or slightly supragingivally. This procedure has been scientifically verified in several reports. Jordan et al (1977) believed that unprepared enamel surfaces may be resistant to acid etching due to the existence of prismless enamel in the superficial layer. Ripa et al (1966) showed this to be 30μm in thickness, and more prevalent in the cervical areas of teeth. Sheykholslam and Buonocore (1972) and Gwinnett (1973) stated that etched prismless enamel results in inadequate resin penetration into the enamel and therefore insufficient resin tags. Other reports have shown that mechanical surface reduction results in a regular enamel surface pattern more conducive to resin tag formation. This finding can be attributed to the removal of the prismless enamel (Barnes, 1977; Galil and Wright, 1979). Schneider et al (1981) found that the mechanical removal of 0.1-0.6mm of the enamel surface of permanent teeth significantly increases the shear bond strength between etched enamel and composite resin. Similarly, debonding of composite from prepared enamel showed more residual composite at the bond site than teeth without mechanical reduction. This was supported by Black in 1985.
In order to uniformly reduce the enamel surface, either depth cutting*, or No.1 round burs** (Fig. 8.5), which measure 0.4-0.6mm from the peripheral aspect of the bur to the shank, may be used as depth gauges prior to gross reduction with tapering diamonds.

The shortcomings of early composite resins prevented their use as labial veneers in the long term. However, Spencer (1972) suggested the acid etch technique for use with acrylic resin, which at that time possessed superior aesthetic properties to composites. Several examples of the acid-etch technique in conjunction with composite resins for the treatment of discolorations were reported, but these mainly referred to its use as a luting agent for preformed acrylic laminates (Stuart, 1975; Widdop, 1979). Direct veneers as they are known today did not exist until the advent of light cured microfilled resins, although the chemically cured varieties were used in the treatment in the enamel defects such as hypoplasia (Mink and McEvoy, 1977).

The clinical technique for direct composite resin veneer placement has been well documented and is generally consistent between authors. Once the treatment plan and diagnosis is confirmed, the method is quite standardised. In all cases, meticulous attention must be paid to the etching technique,

* Komet 834 / 021; 834 / 16, West Germany.
Fig. 8.5. Burs which may be used for enamel reduction prior to veneer placement:

A) Rd. PC 1. (Ash, UK)
B) 834 / 016 (Komet, W. Germany)
C) 834 / 021 (Komet, W. Germany)
particularly with respect to isolation to ensure that the possibility of contamination is minimised. This may be achieved by rubber dam placement wherever possible, to avoid seepage of fluid at the gingival margin.

Prior to isolation, the teeth must be thoroughly cleaned of all plaque and stains with flour of pumice and water, and interproximal debris removed, to ensure the most accurate shade selection possible. Most shade guides supplied with composite materials are grossly inadequate in this application for several reasons. Often, the materials lighten on curing and therefore take on a higher value and lower chroma than the expected shade. In addition, the final thickness of the resin may only be 0.5-1.0mm, which allows background reflection to influence the final result while most shade guides are represented in much greater thicknesses. A misleading result may occur for this reason, since microfilled materials in particular are quite translucent in thin sections, as well as the fact that most shade guides are not made of composite resin. Relatively minor discolorations may be masked by the opaque shades of microfilled or hybrid materials. These resins are less likely to allow background reflection or "shine through" to occur. They achieve the greater degree of opacity by incorporating slightly different fillers from which it may be assumed that the filler in the opaque material has a higher refractive index than that used in the
more translucent material. For example, the translucent shades of Opalux* use a silane-coated strontium aluminoborosilicate glass, whereas the opaque shades have a silane-coated barium aluminoborosilicate glass filler.

Reduction of the labial enamel surface, even of instanding teeth, is recommended to enhance the formation of resin tags as mentioned previously. In cases of severe discoloration, half the enamel thickness may be removed to eliminate or reduce the amount of overcontouring, especially in the cervical area, which may lead to compromised gingival health. The gingival extent of the preparation should be either just at the margin, or slightly supragingival.

Following preparation, the teeth are etched in the manner discussed previously. If adjacent teeth are not to be treated, cellulose or mylar strips should be placed interproximally and carefully wedged to prevent any gingival bleeding. Wedging also assists in adaptation of the strips to provide the correct contour and reduce the tendency for the formation of overhangs or ledges. Once they are etched, a thin layer of enamel bonding agent is placed. This is usually an unfilled Bis-GMA resin with added diluents, which wets the etched enamel surface. It should be thinned with compressed air then light cured. In cases of gingival

* ICI Dental, Macclesfield, UK.
recession and associated dentine or cementum exposure, the use of dentine bonding agents, or a glass ionomer lining which bonds to dentine and which may be etched and veneered with composite, should be used.

Moderate to severe discoloration may be modified by tints or opaquers which may be tested on the tooth surface prior to etching. For teeth which are deeply stained, the colour value of the tooth must be raised, or lowered if the teeth are chalky, or lighter than what appears natural for the patient. Opaquers change the value of the enamel surface to be restored. Similarly, if a tooth needs to be characterised to resemble adjacent teeth, then colour tints should be applied. Colour tints have a low filler content of about five per cent by weight in a transparent resin base which has pigments blended within it. Unlike porcelain surface stains, these are placed beneath the restorative material to reflect through it and provide depth of colour and a greater degree of vitality. For example, a blue tint in the incisal area and yellow-orange placed in the cervical third will enhance the "lifelike" appearance of the restoration. Opaquers are resins which contain a slightly higher filler content (15 per cent by weight) of fumed silica particles which create a highly reflective surface to prevent the background colour from dominating.

Opaquers and colour tints may be used simultaneously to neutralise the existing tooth colour. Using
the subtractive colour concept, the dentist can determine the complementary colour of the stain to be neutralised from the tooth (Faunce, 1983). For example, the complementary colour of a blue-grey tetracycline stain is yellow-orange. Therefore, in place of the bonding agent following etching one or two coats of yellow-orange tint are placed and cured. The result will be a greyish tooth whose colour is effectively neutralised. Opaquer matching the shade of a final composite is then placed to provide the correct background. Once this is achieved, thin characterising coats of tint may be placed to simulate incisal translucency or the characteristic orange-yellow shade of the cervical aspect of a tooth (Fig. 8.6) (Valentine, 1987). A study by McInnes-Ledoux et al (1987) found that several recently marketed tints and opaquers are highly effective, even when used in very thin layers.

The freehand placement of composite is perhaps the most flexible component of the entire procedure, allowing complete control of size, shape and contour (Smith and Pulver, 1982). Light-cured materials offer the advantage of essentially unlimited working time, and the chance to "try-in" a selected composite and check for shade and masking ability. There are two main methods used to placed the composite. The first, as suggested by Black (1982) is that an increment of the material is adapted into a ball and placed in the
Fig. 8.6. The use of tints and opaquers in the placement of direct composite veneers.
centre of the labial surface, then worked towards the margins either by a plastic instrument or finger pressure. Final adaptation is obtained by a flat plastic instrument, and gross excess removed prior to curing. The second method involves the required amount of material being expressed onto a mixing pad and flattened to a thickness of approximately one millimetre which resembles the labial surface of the tooth to be veneered. It is then placed onto the tooth surface and adapted in a stroking motion rather than being patted into place. This assists in achieving correct application of the resin to the bonding agent, and works any entrapped air bubbles to the periphery, where they can be released (Christensen, 1985). The most critical area of this procedure is the requirement of proper gingival contour and finishing margins. If this is carried out by means of enamel reduction and careful attention to contours and margins during placement, final finishing procedures are kept to a minimum, and proper gingival health can be maintained.

Some materials are less viscous than others which renders them more prone to slumping during placement. It is therefore recommended that stiffer, higher viscosity resins are used, which retain their shape and contour prior to polymerisation. A different composite placement method was reported by Fayyad and Wilson (1987). This utilised an impression taken of
the unprepared labial surface in a clear plastic segmental tray. The impression material used was reportedly a semi-transparent silicone elastomeric material of which little information was supplied. Following tooth reduction, the impression was lined with an appropriate amount of composite on the area corresponding to the labial surfaces of the teeth to be veneered, after which it was relocated and reseated in the mouth. The degree of transparency allowed initial curing, the impression was then removed and final curing completed. This method has advantages in retaining the previous labial contours, but obviously needs refinement to become a recognised, routine technique.

As previously mentioned, teeth are not monochromatic. Consequently, veneers may be built in layers, which allows for a gradual change from translucent or bluish incisal shades, through to the yellow-orange hue of the gingival area. If any underlying stains have been well masked, this layering may provide depth of colour if translucent resins are used. It also allows the incorporation of subsurface characterisation, such as enamel white spots or cracks, all of which contribute to a more lifelike, vital looking restoration. Croll and Cavanaugh (1983) simulated enamel defects in order to create a heterogeneous appearance of an entire labial surface, and to achieve visual harmony among adjacent teeth. If layering is to
be contemplated, it is advisable to completely cure the previous layer to avoid undesirable colour blends, or a loss of correct contour. A large area of resin to be polymerised may ideally require a correspondingly wider diameter tip of the light source. Most vary between five and ten millimetres in diameter, but a more appropriate size for treatment of this nature is in the region of 15mm. This ensures a greater area of resin being polymerised a one time, and therefore less likelihood of some areas being undercured. Since few veneers are placed in a thickness of greater than one millimetre, considerations of depth of cure are not of great importance, even though darker shades and opaque composites require longer polymerisation time.

At the completion of polymerisation, finishing and polishing procedures are carried out. Removal of gross excess may be undertaken with narrow tapering diamond or tungsten carbide burs. The water spray which accompanies this allows the veneers and adjacent teeth to show their proper colours, since they appear higher in value when dry. Dry veneers are easily overfinished which may allow underlying discolorations or imperfections to show, or may expose tooth structure (Posner, 1983; Christensen, 1985). Polishing refers to the removal of macroscopic scratches left by finishing techniques and instruments, resulting in a smooth surface or high gloss, depending upon the material used. This is achieved by systematically
decreasing the particle size of the abrasive in the polishing medium. Instruments used in polishing are primarily comprised of discs, impregnated rubber cups, points, wheels, strips and polishing pastes. Some manufacturers advocate the use of water cooling for polishing procedures to avoid overheating of the material or damage to the margins resulting in an unsightly white line. Retraction cord or small flat plastic instruments may assist in providing access to the gingival margin and remove any ledges or overhangs which are detrimental to gingival health (Buquet, 1976; Harding, 1984; Weinstein, 1988).

Although case selection for restorations of this nature is vital, particular guidelines for maintenance should be emphasised to the patient. The medium to long term success of direct composite veneers depends upon meticulous oral hygiene to prevent gingival inflammation and marginal discoloration as well as avoiding the use of excessive incisal force. Hard foods and habits such as pencil or nail biting should be discouraged, and the feeling of large teeth should be explained as being transitory (Smith and Pulver, 1982; Harding, 1984; Christensen, 1985). Examples of direct composite resin veneers are shown in Figures 8.7 and 8.8.
Fig. 8.7. Pre- and postoperative photographs of direct composite resin veneers using a microfilled material*.

(* Silux - 3M Dental Products, St.Paul, USA.)
Fig. 8.8 Pre- and postoperative photographs of direct composite resin veneers using a hybrid material*.

* Herculite XR – Kerr Manufacturing Co., Romulus, USA.
8.3 Indirect Resin Veneers.

Direct composite resin veneers are limited in their success by the dentist's artistic skill and knowledge of the materials used. In addition, since they are fabricated in one appointment, insufficient time allowed for the procedure may result in a less favourable outcome. Consequently, work has continued on indirect veneers which allow greater working time and the chance for a more accurate aesthetic result. Acrylic materials were originally used for this purpose but their popularity has decreased due to poor resistance to wear and abrasion and discoloration with age. Other problems have included the proper colour matching of these materials with adjacent teeth and masking dark discoloration. Faunce and Myers (1976) reported a case in which stock denture teeth of the appropriate shade were hollowed out and bonded to etched enamel using composite resin. Mouradian et al (1976) performed similar treatment on a dentition affected by tetracycline, and published a two-year follow-up report which showed favourable results although significant wear was evident.
The first commercially produced prefabricated veneers, the Mastique Laminate Veneer System*, were introduced by the L.D. Caulk Co., in 1979. These were supplied as poly(methymethacrylate) veneers, approximately 0.2mm in thickness, available in various sizes which allowed them to be trimmed to fit a model of the teeth and by the application of heat, adapt closely to the labial surface. Roberts (1980) stated that this system had a promising future and depending on clinical results believed that the technique should provide a satisfactory interim restoration for children and young adults. Two years later, Roberts (1983) found that the majority of veneers had performed satisfactorily, although a common source of failure had been at the interface between the acrylic veneer and composite luting agent. It was this tendency, and that of gingival irritation that has led to this system becoming less popular. They are also difficult to repair without complete replacement, and are very susceptible to operator variables (Christensen, 1985).

Custom made acrylic resin veneers can be constructed by the usual indirect technique, in which veneers can be fabricated to the precise thickness and contour on a working cast, using heat, pressure, vacuum and direct waxing techniques to achieve a much closer adaptation to the teeth to be laminated than

* L.D. Caulk Co., Milford, USA.
that achieved by selective grinding of a denture tooth. These restorations allow an individual appearance to be created, although they still retain the inherent problems described in relation to the Mastique System* (Avery, 1980).

Indirect veneers were favoured by many practitioners in the early 1980's, since light cured materials were in their infancy, and their predecessors had shown many limitations. There were many reports in the literature concerning the use of denture teeth and stock laminates, most of which were quite similar in their content, generally indicating a cautious optimism towards the procedures involved (Chalkley, 1980; Ronk, 1981; Cheung et al, 1982; Weiner and Rakow, 1983). However, Gourley (1981) indicated that the absence of long-term clinical studies resulted in the necessity to refer to such restorations as temporary coverage only for anterior teeth. In addition, it was stated that preformed acrylic laminates provided problems with overcontouring, proper finish lines, and the possibility of failure of the bonding mechanism. Heyde and Cammarato (1981) stated that when used as indicated indirect veneers should provide a means of treatment for patients whose teeth would either go untreated or undergo less conservative forms of treatment. While the prediction for the long term

* L.D. Caulk Co., Milford, USA.
success of these restorations is difficult, these authors added that their structural durability is limited by the forces applied to them and that their design should be modified accordingly, especially in relation to the incisal edge and protrusive movements. Consequently, it was suggested that if proper case selection, placement procedures and maintenance by the patient were carried out, laminate veneers should last for several years. A follow-up report by de Wet and Ferreira (1984) found that nearly four years after placement, 85 per cent of cases revealed a high success rate in terms of durability and gingival health, with acceptable results in colour stability and surface roughness.

The amount of literature concerning indirect veneers decreased in the mid-1980's which coincided with breakthroughs in microfilled composites and a resurgence of the popularity of direct veneers. The more modern resins were to allow a great improvement in polishing, and their one-appointment procedure attracted the attention of much of the profession. However, it was soon found that despite their advantages, direct veneers largely relied upon the artistic skill of the dentist for their success and required a greater amount of chairside time. Preformed acrylic veneers exhibited problems which led to a compromise being sought. The difficulties encountered included a time consuming and demanding technique, fit
that was only approximate which resulted in varied marginal adaptation and unsatisfactory margins, and premature cleavage of the veneer, usually at the resin-veneer interface. These were overcome to an extent by the use of heat-forming techniques, and the use of various solvents such as methylmethacrylate monomer which increased the penetration and wetting of the laminate in order to improve the bond strength. However, these techniques further complicated an already awkward procedure, and increased the time required for fabrication (Covey et al, 1987; Heymann, 1987).

Several processed composite and acrylic resin systems, for example, "Dentacolor***", "Visiogem***", and "SR Isosit-N***" have been introduced which may be used as indirect veneering materials. Processing techniques may involve light, heat, pressure, vacuum, or a combination thereof, through which microfilled resin materials with physical properties often superior to their chairside equivalents can be produced. This type of veneer also eliminates the need for chairside artistry, and usually results in greater control over contour and shading. Naturally, being microfilled resins, they can be polished to a high lustre which is resistant to plaque and extrinsic

* Kulzer Co. GmbH, West Germany.
** Espe GmbH, West Germany.
*** Vivadent, Schann, Liechtenstein.
stain. Both extraenamel and intraenamel techniques are possible. Although the former are less invasive, they often result in excessive thickness and bulbous contours, and since there is no tooth preparation, etching may not be as effective, as explained previously. However, extraenamel veneers may be indicated for instanding teeth, or where erosion may have dissolved enamel to the point where it is believed that any enamel reduction may lead to exposure of dentine. Alternatively, intraenamel preparations provide a definite finish line and compensate for the thickness of the veneering material thus enhancing proper contours and promoting gingival health (Heymann, 1987). Gross and Malcmacher (1985) previously suggested the use of the same microfilled resin used at the chairside for use as an indirect material, with the veneers being fabricated on working casts and cured by a visible light source.

Almost without exception, the literature concerning all types of veneering techniques places a great deal of emphasis upon gingival health, as criteria for both case selection and post-operative care. Poor gingival health on presentation usually precludes such treatment until it is rectified, and signs of gingival inflammation post-operatively usually requires oral hygiene education, examination of the margins of the restorations, and if necessary,
their replacement. Spinz and Jodaikin (1981) reinforced these ideas, citing the case of a patient who presented with severely discoloured teeth. The patient's smile line did not expose the gingival margins, which allowed the finish lines of the laminate veneers placed to be 1-2mm supragingivally. In addition, the veneers were fabricated to knife-edged margins which limited plaque accumulation in that area and as a consequence, minimised the risk of marginal caries and gingival inflammation (Fig. 8.9 a) (Spinz and Jodaikin, 1981; Goteiner and Sonnenberg, 1982).

An added advantage of supragingival margins is that the potential for moisture contamination, incomplete polymerisation and an absence of enamel for proper bonding may be minimised (Goteiner and Sonnenberg, 1982). However, most authors recommend the placement of a definite chamfer margin 0.5-1.0mm supragingivally which provides a positive finish line yet still maintains adequate thickness required for masking discolorations (Fig. 8.9 b).

Barham et al (1983) studied the gingival response to acrylic laminate veneers and found that if placed at or incisal to the free gingival margin of maxillary anterior teeth, no significant changes in health of the gingivae were produced compared with the control teeth. They found no significant differences between veneered and control teeth in the flow of gingival
Fig. 8.9.  

A) Minimal preparation, knife-edged, supragingival margin.

B) Enamel reduction producing a definite chamfer margin.
sulcular fluid, depth of sulcus, height of free gingival margin, or plaque index. Consequently, they concluded that when used according to the proper techniques, the laminate veneer does not adversely affect the gingiva, provided adequate oral hygiene is maintained. Exner (1985) suggested the use of a clear template, fabricated against a model of the patient's teeth before the commencement of treatment. Following enamel reduction, composite resin is placed in the template and fitted against the teeth following normal bonding procedure. It was found that such a method duplicated the original contours, thereby lessening the potential for compromising gingival health. It was also stated that curing composite resins against a clear matrix provides the best long-term results as far as microleakage and discoloration of the restoration are concerned. However, there were no references cited for this statement and its relevance, especially to the more recent materials, is questionable.

The major shortcoming of indirect veneers, particularly those fabricated from acrylic resin, is the potential for the resin-veneer bond to fail. Boyer and Chalkley (1982) recognised this and attempted to increase the bond strength by pretreating the acrylic surface with various solvents such as methylene chloride, methylmethacrylate monomer and ethylene dichloride. However, the effectiveness of this method was found to be quite technique sensitive. The
significance of bond strength was indicated by Walls et al (1985) who exposed veneer-to-resin samples to simulated environmental conditions. They found that the tensile bond strength of the veneer-resin interface was significantly reduced by both thermal and humidity cycling. Consequently, retention of the veneer was assumed to decrease in the oral environment, with the weakened margins being susceptible to fracture at low load and marginal staining. Therefore, it can be stated that such a clinical procedure has a built-in finite lifespan, which although difficult to predict, ensures the status of such veneers to be temporary.

Bodily discoloration and wear are other disadvantages of resin veneers, which may be attributed to porosity of the materials used. Berge and Hegdahl (1987) found that the most porous were unfilled heat-polymerised acrylic resin and light-activated conventional resins, whereas the least porous were heat polymerised microfilled materials. These authors stated that a dense resin containing fewer pores and voids would give the most favourable clinical results in terms of mechanical, aesthetic and hygienic properties of the veneer. Worn surfaces are characterised by a loss of lustre, presence of scratches and increased surface roughness. This in turn leads to a greater potential for plaque adherence and stain uptake. In addition, Ruyter (1981) stated
that the air incorporated within the voids may affect the polymerisation process and lead to an uneven hardness and therefore produce stress planes. However, the most commonly used materials, the microfilled and hybrid resins, possessed the lowest level of porosity since they are closely packed, have a lower polymerisation shrinkage, and do not include a volatile monomer liquid phase (Berge and Hegdahl, 1987).
8.4 Repair of Composite Resin Veneers.

Dental materials placed on the labial aspect of permanent anterior teeth are subjected to an extremely hostile environment. They must withstand occlusal load in function, abrasion during toothbrushing, and a wide range of transient thermal changes (Longman and Pearson, 1984; Walls et al, 1985). Despite the many advances made in the area of aesthetic dental materials, failures do occur for one or more reasons. Repair of acrylic facings is difficult and usually short term, which ultimately requires the replacement of the restoration. However, repair of composite materials is far more satisfactory and if carried out correctly can significantly increase the lifespan of veneer restorations (Chan and Boyer, 1983; Boyer et al, 1984).

In a study of bond strength following repair of composites, Chan and Boyer (1983) stated that the condition of the surface of the composite is important. They found that bond strengths equal to the strength of the material can be obtained to uncut surfaces 30 minutes old. Cut surfaces that have exposed filler particles resulted in bond strengths of approximately one half the strength of the resin, but it was found that a thin layer of bonding resin greatly improved this. Boyer et al (1984) found that
composites with ground surfaces aged for one week had mean bond strengths after repair of 27 per cent of the cohesive strength of the material without bonding agent, and 48 per cent with bonding agent. The cut surfaces resulted in weaker bonding because of exposed inorganic filler particles and in the case of microfilled composites, exposed pre-polymerised resin particles. Both of these constituents result in a lower bond strength because the number of unreacted methacrylate groups decreases during polymerisation and hence there are fewer potential binding sites.

A study of microleakage following addition of resin was carried out by Chalkley and Chan (1985). These authors found that the addition of light cured composite resin to previously cured material requires a pretreatment of the surface layer using a gel etch and either chemically or light cured bonding agent. This procedure avoids microleakage at the interface and avoids the severe microleakage resulting from saliva contamination. This study also showed that the addition of a different material to that originally used may not be a significant factor, which is relevant if a microfilled material is veneered over a large particle composite; for example, in a Class IV situation.

Incremental addition of different materials is often undertaken to improve aesthetics, strength or surface finish. The results of many studies on this subject have revealed support for the clinical
technique whereby composites of dissimilar compositions are layered for repairs and incremental build-ups (Kao et al, 1988). Thus, it is evident from these studies that if repair of composite veneers is to be contemplated, pretreatment of the "old" surface with etchant and bonding agent is essential.
CHAPTER 9.
PORCELAIN LAMINATE VENEERS.

The benefits of the work carried out by Buonocore and Bowen in providing the dental profession with a simple and effective bonding system are not restricted to composite or acrylic resins. The early 1980's saw this means of bonding resin to etched tooth structure extended to include etched porcelain veneers, following earlier experimental work in this area by Rochette (1975). Porcelain became associated with laminate veneers following evidence of fracture, discoloration and wear with composite and indirect acrylic resin veneer restorations.

The possibilities of veneers have been given a favourable reception in the popular press, especially in publications aimed at the female market which emphasise the advantages of a "Hollywood smile". Emotive advertising and marketing from laboratories and dental supply companies have also contributed to the large wave of interest in porcelain veneers. Consequently, a large amount of literature has also been generated in dental journals, a large proportion of which is aimed at the more entrepreneurial members of the profession and which has little if any, scientific or clinical support. As a result, the dental
practitioner must sift through the more reputable reports, or rely upon his or her own clinical results before a judgement can be made as to whether or not porcelain veneers are the panacea which many articles seem to suggest. Horn (1983b) stated that the theme of modern aesthetic dentistry can be referred to as "the great cover-up". Whether this proves to be complimentary or derogatory depends upon long term results, which, as this is a relatively new treatment modality, are as yet unavailable.

Porcelain laminate veneers are fabricated by indirect procedures, and when made to the appropriate size, contour, thickness and colour are attached to a prepared enamel surface by a combination of mechanical and chemical bonding. The mechanical component is achieved with a composite resin luting agent that also attaches mechanically to an etched porcelain interface. The chemical attachment is achieved via silane coupling agents which will be discussed later in this chapter.

The indications for porcelain veneers are essentially the same as those for resin laminates:

1. masking discoloration
2. enamel defects
3. diastema closure
4. slightly malpositioned teeth
5. contour modification of abutment teeth in removable prosthodontics
6. teeth darkened by age
7. minor enamel cracks
8. unsightly restorations

(Horn, 1983a,b; Christensen, 1985; Barreto et al, 1986; Calamia, 1988; Clyde and Gilmour, 1988; Nasedkin, 1988; Garber et al, 1988). An additional indication was stated by Garber et al (1988) as being suitable in cases of agenesis of the lateral incisor. In this situation, a veneer bonded to a canine may be used to simulate the coronal form of a lateral incisor. In addition, these authors advocated the use of porcelain veneers in those cases of slowly progressing wear patterns. Provided that sufficient enamel exists and that the required increase in length is not excessive, porcelain veneers may be bonded to the remaining tooth structure satisfactorily.

The contraindications for these restorations are not as well documented, but may be summarised as:

1. parafunctional occlusion
2. bruxism
3. oral habits such as tooth-to-foreign-object
4. extremely labially placed teeth
5. mouth breathers because of adverse effects on the gingiva
6. poor oral hygiene
7. denuded dentine
8. insufficient or poor quality enamel
9. malpositioned teeth which preclude insertion of the veneer
10. large diastemata where closure would result in overcontouring
11. broken teeth which may not provide sufficient support. (Christensen, 1985; Clyde and Gilmour, 1988; Garber et al, 1988; Nasedkin, 1988).

Despite the similarities of the indications and contraindications between veneer techniques, porcelain veneers possess several advantages and disadvantages for their use. The advantages primarily revolve around the porcelain material itself, and are as follows:

1. colour stability and optical properties of porcelain
2. greater bond strength than acrylic veneers
3. periodontal health due to reduced plaque adherence
4. resistance to abrasion
5. inherent porcelain strength
6. resistance to moisture absorption
7. maintain surface lustre
8. biological compatibility
9. less uptake of stain than resin veneers
10. superior masking ability

(Horn, 1983b; Christensen, 1985; Barreto et al, 1986; Toh et al, 1987; Covey et al, 1987; Garber et al, 1988).
The disadvantages of porcelain veneers can also be summarised as follows:

1. colour of the porcelain cannot be modified, and may be affected by the luting agent
2. reglazing is not possible, therefore changes in length, contour and margins are limited
3. laboratory costs are involved which make them more expensive for the patient
4. bonding procedure is technique sensitive
5. accurate fit is difficult due to shrinkage of the porcelain
6. only repairable with composite resin and a variation in colour may result
7. the veneers are fragile and subject to fracture prior to or during placement (Horn, 1983b; Christensen, 1985; Barreto et al, 1986; Garber et al, 1988).

Proper case selection is vital to the longevity of these restorations. In addition to the indications and contraindications listed, patients should be correctly educated and motivated to maintain optimal oral hygiene and minimise functional habits (Christensen, 1985). As a result, careful diagnosis and case analysis should be performed pre-operatively. Assessment of the dynamic and static occlusal relationships is the most critical area, especially the contacts between the incisors and canines in function.
which may determine the incisal extent of the veneer margins (Quinn et al, 1986). Evidence of mild bruxism may not necessarily preclude the placement of veneers, provided that sufficient enamel is present, and the patient is forewarned as to the possibility of the veneers becoming dislodged in service (Plant and Thomas, 1987). Clyde and Gilmour (1988) equated the need for a high standard of oral hygiene and the presence of an adequate area of sound enamel available for etching and support as areas of most importance. Enamel provides a hard and stiff base which resists flexing of the tooth that may either crack the porcelain, or break the resin-porcelain bond. Thus, broken down teeth are generally regarded as being unsuitable for porcelain veneer restorations. Proper occlusal analysis may require mounted study models in order to allow appraisal of teeth in edge-to-edge or crossbite relationships (Calamia, 1988).

Porcelain veneers are constructed of a feldspathic porcelain of approximately 0.5-0.8mm in thickness (Millar, 1987; McLean, 1988). Porcelains used in metal-ceramic systems are generally considered to be less suitable for this application, since these materials contain greater amounts of potassium salts which precipitate leucite within the porcelain. It is leucite which increases the coefficient of thermal expansion of the ceramic material towards that of the
alloy, yet also weakens the porcelain, thereby rendering it less suitable for use as a labial veneer (Southan, 1989).

The composition of dental porcelain and its advantages as a dental restorative material have been discussed. However, its ability to be etched has to this point been irrelevant. In 1975, Rochette reported the use of a ceramic restoration bonded by etched enamel and resin for fractured incisors. Simonsen and Calamia (1983) tested the feasibility of etching porcelain and subsequently tested the bond strength of etched porcelain to composite resin. They found that SEM analysis of porcelain surfaces etched for varying periods of time using a solution containing 7.5 per cent hydrochloric acid showed a porous surface. The etched specimens were bonded with unfilled resin and a cylinder of filled composite and the bonds tested. The tensile bond strengths ranged from 0.6 MPa with no etch of porcelain, to 7.5 MPa with a 20 minute etch. Importantly, the cleavage took place through the resin-porcelain interface in the unetched specimens only. This showed that the bond between the etched porcelain and the resin was stronger than either of the individual materials.

In addition to hydrochloric acid, the etching solution used by Simonsen and Calamia (1983) contained hydrofluoric acid, which is widely used in porcelain laboratories. As a result, Horn (1983a) suggested two
methods to etch the porcelain veneer surface. The first required the placement of the veneer into a 10 per cent hydrofluoric acid solution in an ultrasonic bath for 15 minutes. The second and safest method is when the hydrofluoric acid solution is substituted for the solution used by Simonsen and Calamia (1983), in which the veneer is immersed in a ultrasonic bath for 20 minutes. However, Simonsen and Calamia (1983) suggested that further investigations were necessary in order to determine the optimal concentration of etchant and duration of etch. Some manufacturers have recently advocated blasting the porcelain with 50µm aluminium oxide particles in order to roughen the internal fitting of the veneer to create a mechanical bond (Jones et al, 1986; Millar, 1987). However, Jones et al (1986) stated that when viewed under SEM, this surface is roughened but is not as uniformly penetrated or as definitive as one which has been thoroughly etched by a strong acid. Hsu et al (1985) showed that various porcelain processing methods and different etching regimens resulted in a variety of effects. From SEM data, Nathanson (1988) showed that porcelain fired on refractory investment and etched with dilute hydrofluoric acid for 2.5 minutes resulted in the most retentive pattern. This may be due to the variation in surface configuration between porcelain prepared on refractory investment which is relatively rough, and that prepared on platinum foil which
provides a smoother surface. It may also be related to a greater surface area being available for reaction with the rougher porcelain (Stangel et al., 1987). The logical extension of these investigations was to determine whether the type of porcelain had an effect on the etching pattern. Calamia et al. (1985) reported that the shear strengths of samples etched for 2.5 minutes were significantly greater than those etched for 20 minutes. It was also found that feldspatic porcelains produced bonds that were stronger than those produced by aluminous porcelains (Table 9.1). The distinct differences in microstructure produced by various concentrations of hydrofluoric acid suggest that there exists an associated preferential dissolution of one of the phases of porcelain. The higher concentrations appeared to dissolve the glassy phase whereas the lower concentrations (<20 per cent) dissolved the crystalline phase (Stangel et al., 1987).

From the preceding discussion, it is evident that while most porcelains are somewhat similar in their basic formulations, they vary between manufacturers. Therefore, the hydrofluoric acid etching gels must be used in a manner designed specifically for the particular porcelain being used. If this is not followed the result will be a less than optimal bonding surface which may lead to failure of the veneers (Jones et al., 1986).
<table>
<thead>
<tr>
<th>PORCELAIN TYPE</th>
<th>ETCH TIME (5% HF) (minutes)</th>
<th>BOND STRENGTH (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feldspathic</td>
<td>2.5</td>
<td>17.1-21.0</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>5.3-8.3</td>
</tr>
<tr>
<td>Aluminous</td>
<td>2.5</td>
<td>11.0-12.0</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>2.0-3.0</td>
</tr>
</tbody>
</table>

Table 9.1. Bond strengths produced by various etching times using 5% HF on feldspathic and aluminous porcelains.
(Adapted from Calamia et al, 1985.)
In the search for greater bond strength, consideration was given to the use of a coupling agent, following several studies which indicated that the chemical bonds promoted by the use of a silane coupling agent withstood changes of temperature and stress and enhanced adhesion (Rochette, 1975; Eames and Rogers, 1979; Nowlin et al, 1981). Horn (1983a,b) expressed interest, but showed concern due to the limited shelf life of silane compounds. However, Calamia and Simonsen (1984) and Lacy et al (1988) showed experimentally that silane coupling agents enhanced the bond, although they maintained that an etched porcelain surface was of greater importance in the overall bond strength. They concluded that best results were obtained using a combination of an etched surface with a specific silane coupling agent. Similar results were found by Hsu et al (1985) who divided samples into four groups. The variables and shear bond strengths are shown in Table 9.2.

The organofunctional silane coupling agents bond to the silica within the porcelain, leaving a free methacrylate group to bond to the composite resin. Cross-linking of the silane coupling agent also occurs (Millar, 1987; Stangel et al, 1987). Different brands of silane coupling agents have also been investigated showing significantly variable bond strengths between them (Calamia and Simonsen, 1984; Diaz-Arnold et al, 1987). In addition, the resin bond was found to be
<table>
<thead>
<tr>
<th>GROUP</th>
<th>PORCELAIN SURFACE</th>
<th>BOND ENHANCER</th>
<th>SHEAR BOND STRENGTH (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Unetched</td>
<td>None</td>
<td>3.9±0.5</td>
</tr>
<tr>
<td>2</td>
<td>Unetched</td>
<td>Silane</td>
<td>6.7±0.3</td>
</tr>
<tr>
<td>3</td>
<td>Etched</td>
<td>None</td>
<td>20.0±1.0</td>
</tr>
<tr>
<td>4</td>
<td>Etched</td>
<td>Silane</td>
<td>24.0±2.0</td>
</tr>
</tbody>
</table>

Table 9.2. The effect of etching and silane coupling agents upon shear bond strength. (From Hsu et al, 1985.)
weakened by water absorption in the resin (Bailey, 1987; O'Kray et al, 1987). Further simulation of clinical conditions by Thomas et al (1987) revealed that silane treated non-thermocycled specimens had significantly higher bond strengths than silanised specimens which had undergone thermocycling (19.3 and 13.9 MPa respectively).

The question of tooth preparation involving enamel reduction has proved to be somewhat controversial since the inception of porcelain veneers. The two extremes of opinion are centred around either no reduction at all, or a full chamfer preparation on the labial aspect of the teeth extending most or all of the way through the interproximal contact areas. Although several authors argue that it is advantageous if a porcelain veneer can be placed without the need for tooth preparation, most others stress the need for some reduction of the enamel surface.

Garber et al (1988) remained somewhat non-committal in their assessment, stating that each specific case should be evaluated. It was recommended that if periodontal changes are anticipated, some form of enameloplasty is essential. Otherwise, no preparation is necessary. Plant and Thomas (1987) also stated that tooth reduction should not normally be carried out, citing several reasons. Firstly, they believed that the uncertain outcome of facings
warranted a completely reversible procedure, especially as far as incisal reduction was concerned, as reduction in this area and subsequent failure would necessitate the placement of crowns. Secondly, they reported that following acclimatisation, no patient had complained of bulky teeth. Finally, these authors stated that much of the labial enamel of incisors was less than 0.5mm thick, especially in the cervical region of the teeth. Clyde and Gilmour (1988) believe that tooth preparation is unnecessary except in cases of extreme discoloration or labially placed teeth. Similarly, McLaughlin and Morrison (1988) stated that the removal of enamel is in most cases unnecessary, and even counterproductive. In those teeth that did require some enamel modification, these authors stated that only minimal reduction is necessary, to preserve a greater degree of reversibility in the procedure.

Conversely, most authors on the subject favour the concept of tooth preparation prior to the placement of porcelain veneers. Despite the claim by Garber et al (1988) that no scientific data supports either school of thought, many authors who advocate enamel reduction cite references which verify their suggestions. Horn (1983a,b) stated that the removal of labial enamel and the formation of a chamfer finish line would assist in minimising labiolingual dimensions and overcontouring. He added that bonding efficiency is improved if the outer layer of enamel is
removed. This outermost layer is rich in fluoride, and has been shown by Brudevold et al (1956) that enamel fluoride concentration is greatest in superficial enamel. Sheykholeslam and Buonocore (1972), also showed that high concentrations of fluoride adversely affect bond strength. This evidence, combined with the concept of prismless enamel previously discussed in relation to composite resin veneers is indicative of the need for some enamel modification if the resin-tooth bond is to be enhanced. Schneider et al (1981) stated that a reduction of as little as 0.1mm may increase the shear bond strength of composite resin to etched enamel. In addition to the improved adhesive qualities obtained by enamel reduction, this procedure also reduces the likelihood or extent of overcontours which may create an adverse periodontal reaction. Nasedkin (1988) quoted Fankhauser who showed that a linear relationship exists between tooth overcontouring and papillary bleeding index.

Although most authors now recognise the need for at least some tooth preparation, there exists significant variation in the degree and extent of preparation. Horn (1983b) did not stipulate dimensions, but described a preparation in which the cervical finish line was at or slightly incisal to the gingival margin, and where the incisal extent was finished short of the incisal edge. Calamia (1983) suggested a similar preparation, but included a slight
incisal overlap to assist in proper seating of the veneer. In 1985, Calamia suggested a slight chamfer in enamel 0.5mm deep, and 0.5-1.0mm supragingivally. The mesiodistal extensions were also stated as being 0.5mm deep, but finishing slightly labial to the contact areas. Quinn et al (1986) reiterated Calamia's suggestions, but substituted the slight incisal reduction for a definite 0.75-1.0mm reduction. These dimensions have been substantiated by most authors with only slight variations necessary depending upon the position of each tooth relative to the arch. For example, rotated teeth may require slightly greater reduction in certain areas if correct alignment is to be achieved (Rosen and Milstein, 1986; McLean, 1988; Nasedkin, 1988). McLean (1988) explained incisal reduction as being desirable since it assists in seating of the veneer, and Calamia (1988) added that the overlap hides the incisal margin, provides greater porcelain bulk for added strength, and reinforces the incisal edge without subjecting the margin to possible shear forces. An example of a preparation for teeth requiring porcelain veneers with minimal incisal reduction is as shown in Figure 9.1. Brooks (1987) added that general considerations should include smooth, rounded surfaces, and that all finish lines should be visible in order to avoid undercuts, and that all these finish lines be definite and continuous.
Fig. 9.1. Clinical appearance of tooth preparation for porcelain veneers.
Labial reduction should be undertaken first, to the dimensions discussed. In the case of a rotated tooth, judicious reduction should enable the veneer to simulate correct arch alignment (Fig. 9.2). However in this situation it is possible that dentine may be exposed. In small amounts, this is not critical, provided that the margins are not involved, and that they remain within enamel. Exposed dentine is susceptible to the effects of the acid-etching solution and if unprotected may lead to pulpal hyperaemia or even necrosis. Consequently, exposed dentine must be covered during the etching process, with either a dentine bonding agent, glass ionomer, or calcium hydroxide materials. Dentine bonding provides only a fraction of the bond strength possible with enamel bonding and a less effective seal. In addition, polymerisation shrinkage of the resin may result in forces that exceed the strength of the resin bond to dentine, thereby resulting in a contraction gap at the resin-dentine interface. Suzuki et al (1989) reported that a study of several types of dentine bonding agents showed a failure of these materials to provide interfacial continuity between the resin and the dentinal component of the cavity preparations. Consequently, exposure of dentine in the marginal area of veneer preparations is likely to cause microleakage, postoperative sensitivity, recurrent caries, marginal staining, and eventual loss of the
Fig. 9.2. Method in which veneering may be used to simulate correct arch form.
restoration. McLean (1988) suggested the use of glass ionomer cement to cover exposed dentine. To facilitate this, it was recommended that the removal of 0.5mm of dentine would provide sufficient thickness of material. This is supported by Suzuki et al (1989) who found no gaps between dentine and glass ionomer when used as a lining material in shallow Class V cavity preparations. However, these authors stated that glutaraldehyde based dentine bonding agents provided the best results. Calcium hydroxide materials are useful in protecting dentine during etching, after which they may be removed to prevent shine-through, and to facilitate the bonding of the resin luting agent to the tooth structure.

In order to reduce the possibility of dentine exposure, meticulous attention must be paid to the enamel reduction procedure. Since the enamel is thinnest in the cervical region, supragingival margin placement is imperative, and reduction must not exceed 0.5mm. Therefore, it is advisable to use some form of depth gauging, either by depth cutting burs similar to those described in the previous chapter, or by cutting grooves of the required depth which are subsequently joined. Measurement of these grooves can be achieved by using a No.1 round bur*, which is 0.4mm from the peripheral aspect of the bur to the shank, or by

* Ash Rd. PC 1. UK.
pre-measuring a tapering round ended diamond instrument.

Reduction of the remaining labial enamel may be performed in two stages. Firstly the bulk of the reduction is made using a coarse diamond instrument which provides a rough surface which both assists retention (Aker et al, 1979) and reduces reflection of the underlying tooth structure through the porcelain (Garber et al, 1988). Secondly, the marginal areas should be finished with either a fine grit diamond or tungsten carbide finishing bur to create a definitive smooth finish line to enhance the seal at the periphery.

As mentioned previously the interproximal margin should finish just labial to the contact area, yet remain virtually out of sight within the embrasure area. This provides a wrap-around effect which enhances retention. Garber et al, (1988) stated that the extent of the proximal preparation may be influenced by the method of fabrication to be employed. The use of platinum foil matrices require the split-die technique, which provides problems when sawing the individual dies if the preparation is in close proximity to that area. Consequently, the contacts may be modified prior to impression taking to facilitate separation of the dies by a "snapping" technique. This involves the use of an abrasive strip to reshape the contact rather than separating the teeth.
Incisally, the preparation should display a definitive flattening of the incisal edge of approximately 1mm. Analysis of study casts prior to preparation should determine functional movements and therefore the lingual extent of the incisal finish line. This will avoid finishing the veneers in areas which are subject to shear stresses across the junction of the porcelain and tooth which may lead to porcelain fracture and/or debonding in this area. The lingual extent of the incisal reduction should be finished as a chamfer margin to allow sufficient porcelain thickness in this area. The remaining thickness of enamel in the incisal area then acts as a stiff base for the porcelain, which reduces the tendency of the porcelain to flex and cause catastrophic failure (Southan, 1989). Following the reduction procedures, all line angles should be rounded to reduce stress concentration and the propagation of microcracks in the porcelain.

In keeping with indirect procedures, an accurate impression must be taken of the prepared teeth from which a master cast is fabricated. Prior to impression taking, gingival retraction may be required if the margins closely approach the gingiva. However, since it is usually recommended that margins be kept supragingival, retraction is not often required (Barreto et al, 1986). Calamia (1985) stated that any elastomeric impression material that can be used for
multiple pours is acceptable. Poly(vinylsiloxane) impression materials are used in the conventional two-phase method and are recommended by most authors. Reversible hydrocolloid materials have been accepted for use by Millar (1987) but these materials have three main disadvantages. Hydrocolloid has a relatively low shear strength, which may render it subject to tearing in the unprepared undercut areas below the contact areas within the embrasures. These are normally removed in conventional crown preparations, which suggests that an elastomeric material with greater tensile strength is more desirable. The second disadvantage of a hydrocolloid impression is that it may distort during the exothermic reaction of phosphate-bonded refractory investment used in the refractory die technique during fabrication of the porcelain veneers (Garber et al, 1988). Thirdly, multiple pours are not acceptable.

Following the impression taking procedures, a decision must be made regarding the necessity of temporary restorations. In general, temporary veneers are not required since the preparation should be entirely within enamel with no exposed dentine present. Therefore, the patient should experience little or no sensitivity and only minimal aesthetic problems. In addition, rushed or badly contoured temporaries may lead to gingival inflammation which may hinder the bonding process. Similarly, the gingiva may be damaged during their removal. However, some
situations may require interim coverage, especially if dentine has been inadvertently exposed, or contacts opened which may result in the teeth drifting between the preparation and insertion appointments. Aesthetic compromise may also demand the use of temporaries, especially in the case of tetracycline staining, whereby the thinner prepared enamel allows the stained dentine to become more visible. Garber et al (1988) also suggested that temporary veneers be placed on mandibular incisors with an incisal overlap preparation to prevent overerruption.

The most common method of temporising veneer preparations when indicated is by direct placement of composite resin. Most authors agree that composite resin should be placed directly on the prepared enamel without etching or bonding resin (Calamia, 1985; Millar, 1987; Calamia, 1988; McLaughlin and Morrison, 1988). Millar (1987) stated that the "wrap-around" effect and resin placement into the embrasure areas ensures sufficient retention for the short time that the temporaries are required. However, Rosen and Milstein (1986) found that temporary veneers placed over unetched enamel were lost within 48 hours. To counteract this, Boksman (1986) and Brooks (1987) suggested that a small area in the centre of the labial surface be etched to provide "spot bonding" to retain the temporary veneer. If the margins are avoided, the preparation will not be affected and its
removal should be simple and therefore not complicate fitting of the final porcelain veneers. Willis (1988) described a method for fabricating temporary veneers using a vacuum-formed clear vinyl template. If the original shape and position of the teeth are to be retained following veneer placement the template can be fabricated on the original study cast. However, if tooth shape and contour and its position in the arch are to be modified, this can then be waxed on the study model, duplicated, and used for the fabrication of the template. This is then used as a matrix for composite resin which can be light polymerised through the clear material, after which it is removed and "spot bonded" onto the preparations. Garber et al (1988) described a similar technique using acrylic resin.

The method of shade selection for porcelain veneers is similar to that used in metal-ceramic or all-ceramic crown procedures if several veneers are to be placed adjacent to one another. However, attempting to match one veneer to the whole dentition, particularly if it is used to mask an underlying discoloration is often difficult. The problem lies in the need to mask the discoloration, while simultaneously attempting to reproduce a life-like, translucent tooth, in a restoration approximately 0.5mm thick. In this situation, the shade tab selected may be easily matched by the technician, although the final shade is
often altered and influenced by the original tooth colour, the amount of opacifier, the shade and opacity of the composite resin luting agent, and the use of resin shade modifiers and characterisation beneath the veneers (Garber et al, 1988).

Once the impression has been taken, it is sent to the laboratory for fabrication of the veneers. The two methods used for this are the traditional platinum foil matrix, and a refractory investment material which is used as a foundation for the veneer construction. The platinum foil technique has been favoured by a slight majority of authors, probably as a result of familiarity carried over from porcelain jacket crown construction (Horn, 1983a,b; Calamia, 1985; Rosen and Milstein, 1986; Quinn et al, 1986; Plant and Thomas, 1987; McLean, 1988; Nasedkin, 1988; Garber et al, 1988).

The cast is pinned in the usual manner for removable dies. Individual dies are produced by sectioning the cast from the base towards the incisal edge, leaving the cut short of the contacts, since saw blades will destroy the contacts of the dies. Final separation can be achieved by snapping the dies through the contact area, either by having modified the contacts in the mouth or by a careful cut on the lingual surface of the cast, allowing the dies to be snapped without affecting the labial surface or the
contacts. The dies are then trimmed in the usual manner, allowing access to all margins of the preparation.

Platinum foil is cut into a triangular shape, which is then applied to the die, leaving an apex of the triangle below the labial gingival margin. It is then burnished into intimate contact with the die, and all excess foil beyond the margins trimmed, leaving a prepared platinum foil matrix. The foil may then be removed from the die using the tab on the labial side and rotating it around the incisal edge. It is then held in a flame until it glows in order to decontaminate and anneal it. The foil then has a matt finish, and is readapted to the die and secured with several peripherally placed drops of sticky wax. Close adaptation of the foil is paramount, so a soft pliable foil, no thicker than 0.025mm is required.

The second method of fabricating porcelain veneers is the refractory investment technique (Barreto et al, 1986; Garber et al, 1988; Clyde and Gilmour, 1988). A master cast is produced from the original impression in the same manner as that for the platinum foil technique. A refractory investment material with a coefficient of thermal expansion similar to that of the ceramic to be used for the porcelain veneer is chosen. If they are dissimilar, a disproportionate amount of expansion during firing may occur, which may lead to an inaccurate fit or even
fracture of the final restorations. The master cast should be surveyed for undercut areas which should be blocked out to allow for fitting and placement of the finished veneer. An elastomeric impression is then taken of the veneer preparations using a sectional tray, or the master cast may be duplicated with hydrocolloid (Barreto et al, 1986; Garber et al, 1988), and a cast using the refractory investment material is produced.

Either a complete refractory cast or separate removable dies may be used in this technique. The refractory cast should be trimmed as much as possible to reduce the amount of ammonia gas released by the material during heating. A degassing procedure is undertaken to minimise the risk of contamination of the ceramic material by the liberated gas. First, the cast should be dried and heated by placing it in front of the open muffle of a furnace. It is then placed inside the furnace, with temperature elevated to 650°C without vacuum and held for 20-25 minutes. This process removes excess ammonia from the cast; therefore, a vented furnace should be used to prevent gas escaping into the working atmosphere.

After the initial degassing and heat soaking procedure, the cast is placed in a porcelain furnace under vacuum and brought to 1050°C by raising the temperature at the rate of 25-30°C per minute. This temperature is held for approximately two minutes after which the vacuum is slowly released and the
temperature gradually reduced to room temperature (Barreto et al, 1986; Garber et al, 1988). When the cast has cooled, it is soaked in distilled water for four to five minutes to prevent the applied porcelain from drying out excessively. This is also prevented by the application of a sealant to the cast in all porcelain bearing surfaces and margins. Usually, such a sealant is simply a slurry of the veneering porcelain, which is applied beyond the labial margins to achieve a favourable peripheral seal.

The application of the porcelain is essentially the same for both the platinum foil and refractory investment techniques, and will be discussed shortly. Following porcelain build up, the veneers are glazed or fire-finished and bench cooled, after which any excess is removed. All refractory material is removed until only a minimal amount remains. This can then be blasted with 20-50μm particles of aluminium oxide at 40psi to remove the excess material. The veneers are then cleaned in an ultrasonic detergent bath for three minutes, then trimmed and polished with a rubber wheel and tried on the master cast to determine any necessary final adjustments.

The first application of porcelain should be 0.3-0.4mm thick, which usually results in shrinkage and cracking following the first firing. These cracks and fissures will be filled in during the second or third application of porcelain which should result in
the final contour. The platinum foil technique usually requires only two applications, whereas a third is necessary with the refractory investment technique in order to achieve the desired form. Garber et al (1988) stated that aesthetics are enhanced if the porcelain is built up in gingival, body, incisal and enamel stages, after which the porcelain is condensed and contoured to its desired shape and then allowed to bench set for five minutes before firing.

Upon cooling following removal from the furnace, excess may be removed, or the surface shaped and characterised using diamond burs. Only microfine high speed diamond instruments should be used, since larger grit sizes may chip the brittle porcelain. Facial areas may be contoured using a flame shaped diamond, whilst marginal areas are lightly contoured with fine abrasive discs. If any characterisation is required, it should be performed at this stage. Once it is completed, the veneers are glazed, usually with a thin layer of porcelain glaze which is painted onto the labial surface to seal any microporosities and achieve a natural lustre. Surface stains may also be added at this stage (Barreto et al, 1986; Garber et al, 1988).

Several authors state no preference for either the platinum foil or refractory investment techniques (Millar, 1987; McLean, 1988; Nasedkin, 1988). Calamia (1985) suggested that although it was originally
thought that the refractory cast would produce a superior veneer, clinical experience has shown no significant difference between these techniques. However, McLean (1988) stated that the construction of accurately fitting veneers is difficult with either technique. He added that all porcelain powders have a volume porosity of 38-40 per cent which makes shrinkage control difficult, even in the hands of an experienced technician, leaving a marginal accuracy of 20μm at best, with most having marginal gaps of around 100μm. These open margins are filled with composite resin luting agent, but this is subject to wear and dissolution which may lead to debonding or marginal staining. McLean (1988) also suggested a method of compensating for this shrinkage whereby a very thin layer of aluminous core porcelain is laid down on the refractory die (if this method is used), which after firing, does not produce fissures. Consequently, the veneer porcelain is stabilised, and subsequent layers of porcelain do not crack. If the margins are finished under magnification, gaps of less than 25μm can be achieved.

After the veneers have been fired and finished, they must be etched to enhance the resin-porcelain bond. The rationale for this procedure has been discussed, while the actual laboratory steps are described in the following paragraphs.
The finished veneer must be etched on the minor, or concave surface only, which necessitates protection of the labial surface. Barreto et al (1986) recommended the attachment of sticky wax to this surface, which acts as a handle and a barrier to the acid. Any remaining exposed porcelain must also be covered. Garber et al (1988) suggested that the labial surface be attached onto a clay strip, allowing the concave inner aspect of the veneer to act as a reservoir into which the etching gel is placed and allowed to stand for seven to ten minutes. The etchant should be occasionally brushed up to the margins to ensure proper coverage and to prevent pooling and inadequate etching of that area. The etchant must then be removed, either by thorough washing in running water (Barreto et al, 1986) or by neutralisation in a sodium bicarbonate solution (Jones et al, 1986; Garber et al, 1988). The veneers are cleaned in an ultrasonic detergent bath and dried. The etched veneers exhibit a frosted appearance which is quite distinct from the glazed, unetched labial surface.

One of the first reports of the use of a composite material as a means to secure porcelain was by Eisenbrand (1975) who incorporated a composite backing with a porcelain pontic which was then etched and bonded to the abutment teeth. Since the advent of porcelain veneers, the etching of porcelain and the use of silane coupling agents and composite luting agents have refined the procedure somewhat.
The actual clinical procedures for placement of porcelain veneers has been well documented and are generally consistent between authors. Prior to the final luting of the veneers, a careful try-in process must be undertaken, which involves a check for individual fit, evaluation of collective fit if more than one veneer is to be fitted, and an assessment and modification of the final colour. The teeth should be isolated, any temporaries removed, then cleaned with a pumice and water slurry to remove plaque and pellicle. The contact areas may be cleaned with a fine composite finishing strip, and the patient reclined into a supine position to reduce the likelihood of the veneers being dislodged due to gravity during the try-in procedure. The veneers should be checked on the master model for marginal fit and any binding with adjacent veneers. Contact with the master model is not detrimental to the etched surface (Clyde and Gilmour, 1988). They are then individually assessed in the mouth, with emphasis on undercuts and excessive contact point impingement. If the individual fit is satisfactory, interproximal contacts are confirmed by placing all veneers simultaneously. Placement of veneers should not require force, but they should fit passively onto the preparations.

The final colour of the restoration is the combination of several factors, these being the original tooth colour, the porcelain shade selected
and the amount of opacifier used, the shade and opacity of the composite luting agent, and the use of shade modifiers and surface characterisation techniques. Consequently, all of these variables must be included in a try-in procedure if it is to be correctly assessed. The modification produced by the luting agent is perhaps the most critical, and must be evaluated prior to bonding. Garber et al (1988) suggested that if the veneer appears darker than the original shade tab selected when placed into position, then a lighter coloured luting agent is required, and vice versa. Despite this statement appearing obvious, it eliminates a significant number of luting shades, and the correct range can then be determined.

The luting agent is selected, placed on the veneer and reseated without curing. Although minor colour change may occur after polymerisation and in the moist oral environment, the colour stability of most modern composite resins renders such changes essentially imperceptible. Many types of composite resins have been used as luting agents, ranging from microfilled to small particle macrofilled, and hybrids. In addition, resins of high and low viscosities have been advocated as ideal. Friedman (1987) stated that contrary to common opinion, luting agents of high filler content may be less likely to induce fracture of the veneer than those of lower viscosity. The reason given for this is that the
thixotropic nature of the higher viscosity materials allows more accurately controlled seating of the veneer. However, it is generally believed that lower viscosities are preferable. A comparison of some of the more common brands of composite luting agents is seen in Table 9.3.

Although composite luting agents are available as light cured and chemically activated systems, light cured materials are more versatile, in that they allow try-in, modifications to shade and final colour check prior to final seating. In addition, gross excess is more easily removed before final curing, which facilitates easier polishing and trimming of the margins. However, a potential problem exists in using a light cured luting system if an opaque or thick veneer is used, since insufficient light or inadequate intensity may prevent polymerisation. In such situations, dual cure systems are indicated, in which chemical and light initiated polymerisation takes place.

The actual veneer placement procedure begins with the patient being placed in the supine position. Retraction cords may be placed to improve access to marginal areas and to reduce the flow of crevicular fluid which may contaminate the bonding procedure and produce an inadequate seal. However, care must be taken in placement of the cord not to initiate gingival bleeding, either from excessive force or due
<table>
<thead>
<tr>
<th>NAME</th>
<th>METHOD OF CURE</th>
<th>PARTICLE SIZE (μ)</th>
<th>FILLER LOAD (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Durafill Flow*</td>
<td>VLC</td>
<td>0.04</td>
<td>52</td>
</tr>
<tr>
<td>Dual**</td>
<td>VLC/Chem</td>
<td>1.0-5.0</td>
<td>60-62</td>
</tr>
<tr>
<td>Ultra-bond***</td>
<td>VLC/Chem</td>
<td>3.0-3.5</td>
<td>75-80</td>
</tr>
</tbody>
</table>

N.B. VLC = Visible Light Cured  
Chem = Chemically / Self-cured

Table 9.3. Comparison of properties of various composite resin luting agents.

* Kulzer, West Germany.  
** Ivoclar/Vivadent, Schann, Liechtenstein.  
*** Denmat, Santa Maria, USA.
to inflamed gingival tissue produced by inadequate oral hygiene or poorly fitting temporary veneers. Following this, the etched surface of the veneers is treated with a silane coupling agent to enhance the adhesion between the porcelain and composite luting agent. The most effective formulation is a hydrolysed silane which requires no mixing or preparation. In the non-hydrolysed form, the surface of the veneer is conditioned with an acid medium which activates and hydrolyses the subsequent layer of silane coupling agent. The preactivated formulation is simply painted onto the etched porcelain surface and allowed to dry for approximately one minute, after which the excess alcohol vehicle is gently evaporated with a stream of uncontaminated air, leaving a dry, silane-coated veneer. The teeth are then isolated, usually by means of saliva ejectors and cotton rolls. Use of rubber dam is ideal, but may present difficulties in obtaining access to margins. Moisture from exhaled air can be minimised by nasal breathing or by the placement of gauze posteriorly.

Following thorough prophylaxis with pumice and water, the teeth are etched in the conventional manner, using 35-37 per cent phosphoric acid, ensuring that all margins are covered with etchant. Horn (1983b) advocated gels for this purpose, since liquid etchant may flow into the gingival crevice. However, Garber et al (1988) stated that liquid solutions are
more easily washed away than gels, since the methyl cellulose component of gels may remain in the etched enamel pores and act as a contaminant to the bonding procedure. As with all etching procedures, it is imperative that no contamination occurs, either from saliva or air lines. Any exposed dentine is protected from the etchant by calcium hydroxide which is then removed, or by a glass ionomer material. Unfilled resin is then placed in a thin layer onto the enamel surface, then cured to seal the enamel. This step is then repeated on the etched and silane-coated surface of the veneer. The composite luting agent is expressed onto the centre of the veneer and spread laterally to prevent entrappment of air. When placing multiple units, the most distal are first seated working mesially to the canine. The two central incisors are then placed, to ensure correct fit and colour match. Any discrepancies may then be accommodated by the lateral incisors. Each veneer is placed separately, with cellulose strips fitted interproximally to prevent excess luting agent from flowing into the contact areas and to allow some shaping of the proximal surfaces. Once the luting agent has been placed, the veneer is rotated onto the buccal surface and gently manipulated until contact is made in the region of the gingival finish line. The motion must be a gentle rocking movement which slowly allows excessive composite material to extrude from all sides.
of the veneer. A sliding motion must be avoided, since contact with the incisal edge may wipe the internal aspect of the veneer clean of the luting agent, leaving a void. It is this part of the procedure which discourages the use of high-viscosity luting agents, since materials of this nature act as a fulcrum under the brittle porcelain. As a result, excessive manual pressure in attempting to seat the veneers may lead to fracture (Done, 1987).

The aim of veneer cementation is to minimise the exposed resin margin. This is related to the film thickness, which is at its theoretical minimum when equivalent to the diameter of the actual filler particles. As discussed previously, particle size is directly related to filler content and therefore, viscosity. Because low filled composites are less viscous, they are usually preferred to more highly filled materials. Although the latter have disadvantages, their superior properties of colour stability and resistance to water sorption cannot be ignored. A compromise could be reached if the higher viscosity materials were more easily manipulated. This can be achieved if the thixotropic nature of composite resins is recognised. This allows the viscosity to be reduced when shaken or when subjected to shear force. Once such stimulation is removed, the original viscosity returns. Therefore, a non-traumatic oscillating device would be useful in taking advantage of this property
to use superior materials as luting agents, while simultaneously reducing the potential for veneer fracture.

Once the veneer has been positively located, it should be firmly held in place and partially polymerised for approximately 5-10 seconds. It is important that firm seating pressure be maintained, since pressure release may cause a vacuum beneath the restoration, thereby drawing in luting material and creating a void at the margin. Following the initial polymerisation, gross excess of composite may be removed with a scaler or probe. Polymerisation is then completed for at least two minutes since the light must penetrate the porcelain and remain until adequate curing is achieved. Curing time may be increased if resins of low value or high opacity are used. It should also be noted that most light curing units undergo a continual decrease in intensity, especially those utilising fibre optic cables, which may crack during use. In addition, it is preferable that the diameter of the tip be in the range of 10mm or more, in order to expose larger areas of the tooth to the curing source.

Finishing procedures commence with the removal of any remaining excess composite resin with a sharp carving instrument, and management of minor marginal discrepancies with a high-speed tungsten carbide finishing bur, ensuring adequate water coolant is used
to prevent the effects of heat both to tooth structure and the composite luting agent. The cervical areas may then be polished with diamond-impregnated paste which will produce a high lustre and decrease the potential for plaque adhesion. Finishing strips are used interproximally, in the conventional manner. Similar procedures are undertaken on the lingual aspects of the veneers if incisal coverage was indicated (Garber et al, 1988).

In contrast to the aforementioned finishing techniques, Friedman (1987) believed that the use of rotary instruments following cementation in the marginal areas should be avoided. He stated that marginal integrity may be compromised, microscopic crack lines created, and cementum damaged. It was added that properly constructed veneers should require no more finishing than removal of excess composite resin with a sharp instrument. An interesting observation was made by Tay et al (1987), who found that the removal of excess luting agent with a fine sable brush moistened with bonding resin also sealed any gaps and produced a smoother margin than that achievable through polishing. However, it is likely that this would be lost in normal function, and any benefits limited to the short term. Haywood et al (1988) stated that although mechanical finishing of veneer margins corrects marginal defects, it removes the surface glaze which promotes plaque adhesion unless the porcelain can be polished to an acceptable
smoothness. These authors used scanning electron microscopy and specular reflectance to compare various polishing techniques with glazed porcelain. It was found that finishing with a fine diamond instrument followed only by diamond polishing paste produced an unacceptable surface. However, the use of a series of diamond finishing burs of progressively finer grit followed by a 30-fluted tungsten carbide bur and diamond polishing paste achieved a finish equal or superior to the smoothness of glazed porcelain (Haywood et al, 1988). Figure 9.3 shows a case in which porcelain veneers were indicated.

The very nature of porcelain veneers limits the extent to which natural teeth can be simulated. It is impossible to mask stains, then duplicate natural translucency in a restoration which is in the vicinity of 0.5-0.7mm in thickness. In addition, single veneers are difficult to accurately match to the existing teeth, as mentioned previously. Reid (1988) addressed this problem and attempted to formulate a technique which can overcome shade mismatching and provide consistent, acceptable results. This involves the neutralisation and enhancement of the discoloured area prior to cementation of a "non-opaqued" veneer. In this technique, a colour wheel is used to find the opposing colour to that of the discoloration. For example, a yellow-orange discoloration has a bluish shade opposing it. Application of a lightly filled,
Fig. 9.3. Pre- and postoperative views of treatment by porcelain veneers.
translucent, pigmented Bis-GMA material in thin layers is used to neutralise the discoloration to a shade of grey, which is of lower value than the remainder of the dentition. In order to raise the value, Reid suggests colour enhancers, which are also lightly filled, pigmented Bis-GMA materials, of a shade which complements the tint and can be matched to a commercial shade guide. Once this base is achieved, a non-opaqaed veneer can be bonded with a translucent luting agent which provides depth and translucency to the restoration. Reid claimed that this method overcomes the awkward problem of matching one or two veneers to an otherwise unaffected dentition.

McLean (1988) noted that their limited thickness prevents the segmental layering and building techniques possible in the construction of all-ceramic and metal-ceramic crowns, which leads to the veneers appearing monochromatic. Thus, given the amount of publicity now existing in the popular press, the public are becoming conditioned to accepting monochromatic "white" teeth which they believe will enhance their appearance. With this in mind, it is essential that the building of porcelain veneers reflects the need to reproduce natural teeth. Consequently, it is now evident that rather than attempting to mask underlying discoloration and simulate translucency at the same time, the stains should be first masked or neutralised, with depth of
colour and translucency provided by the porcelain (McLaughlin, 1987; Nasedkin, 1988; Garber et al, 1988). Nasedkin (1988) recommended that glass ionomer material be placed over areas of severe staining providing an effective opacification for the porcelain. This technique would only be desirable in areas where dentine had been exposed, and not in cases of widespread discoloration, since the proper mechanism of bonding composite resin to enamel would be prevented.

In contrast to the freehand buildup of direct composite veneers which may approach up to one millimetre in thickness, the porcelain veneer is fabricated to precisely fit the prepared tooth, often leaving a space of 40-50µm between the tooth and veneer. Obviously, most layering of colour is therefore achieved within the porcelain. Consequently, the role of the luting agent as a contributor to aesthetics in porcelain veneers is limited to minimal coverage of offending stains and possibly to the alteration of the value of the previously discoloured surface (McLaughlin, 1987). Adar (1988) suggested a method for neutralising the dark underlying colour while still providing a degree of natural translucency to the porcelain veneer. Opaque porcelain is mixed with a dentine shade to act as an initial masking layer. This allows penetration of some underlying colour to the surface which creates a depth of colour,
and yet allows incident light to be reflected from the opaque particles to the surface. A superficial layer consisting of cervical, body and incisal porcelains is added to the initial layer. However, a veneer of less than one millimetre in thickness is extremely unlikely when fabricated in this way, which reintroduces the probability of overcontouring. Alternatively, surface characterisation may be utilised to produce incisal and gingival effects which reduce the monochromatic nature of porcelain veneers.

Despite their many advantages, porcelain veneers may fail for several reasons. Since these restorations are placed primarily for aesthetic reasons, they may be considered to be failures if an unacceptable shade match, or incorrect aesthetic contouring occurs. The perception of what is visually pleasing is subjective, and as the patient is responsible for their own appearance and general presentation, they are ultimately the sole judge of such a matter; a fact that the practitioner must accept. Physical failures may also occur, by means of marginal discoloration and microleakage, fracture, and failure of the bonding and retentive mechanism. Many of these difficulties can be addressed by thorough preoperative occlusal analyses, proper construction of the laminates, prevention of moisture and saliva contamination, and meticulous attention to all components of the physical and
mechanical bonding procedures. Postoperative instructions regarding diet and oral habits will also assist in reducing the potential for failure (Ronk, 1982).

The question of microleakage is an important one. If this occurs, secondary caries and marginal staining are the most likely sequelae. Other factors than moisture contamination and poor technique may be responsible for producing microleakage. As discussed in the previous chapter, human enamel is influenced by the ingestion of fluoride, particularly surface enamel. The existence of prismless and fluoride-rich surface enamel will reduce its etching potential, particularly in the cervical area where marginal integrity is of greatest importance. In addition, enamel is at its minimum thickness in this area of the tooth. Thus, it is vital that care be exercised in the enamel reduction stage, to prevent dentine exposure and total removal of enamel which would otherwise provide the necessary seal. In cases where the luting agent wears or absorbs stain without compromising marginal integrity, Helpin (1985) described a technique similar to some bleaching procedures which removes marginal staining without compromising the integrity of the veneer.

Fracture of porcelain veneers may occur as a result of direct occlusal forces or indirectly applied force. Teeth possess a degree of flexibility whereas porcelain is a brittle, inelastic material. When
placed over a well supported base, porcelain is able to withstand normal occlusal forces associated with anterior teeth. Conversely, when applied to a flexible base, brittle porcelain may be exposed to forces which are sufficient to cause fracture. This may be significantly lower than the inherent strength of the material when microcracks exist within the porcelain which propagate on exposure to load (Toh et al, 1987; Southan, 1989). Highton et al (1987) described a photoelastic study of stresses on porcelain veneer preparations and found that incisal, labial, proximal and gingival reduction is recommended for patients with Class I occlusions. They stated the need for gingival tooth preparation to control stress distribution and provide the best potential for periodontal health.

Repair of fractured porcelain: is made possible with varying degrees of success by the same mechanism used to bond veneers to tooth structure with composite resin. Newburg and Pameijer (1978) were among the first to test repair of porcelain with composite resin. They found that silane coupling agents increased resistance to shear forces. Highton et al (1979) studied two commercial "porcelain repair" systems and found that the use of acrylic resin following silane coupling provided greater strength than composite bonding resin used with silane coupling.
Nowlin et al (1981) found that only 18 per cent of the original strength was regained following repair, indicating that the use of this procedure was temporary. However, Barreto and Bottaro (1982) stated that success can be increased by creating mechanical retention, bevelling, etching and silane coupling the porcelain prior to repair with microfilled composite resin.

Much of the theory behind the application of porcelain repair systems has evolved from the mechanism of the porcelain-silane-resin-tooth bond. Nayyer et al (1985) tested four "porcelain repair" materials and found that they separated from the porcelain. Diaz-Arnold et al (1987) concluded that these systems significantly increased the resin-porcelain bond, primarily through a roughened porcelain surface and the presence of a silane coupling agent. Acidulated phosphate fluoride (APF) gels of 1.23 per cent concentration have been reported to etch the surface of porcelain to clinically acceptable levels in several minutes (Sposetti et al, 1986). Due to the highly caustic nature of hydrofluoric acid, intra-oral porcelain repairs may be performed by using 1.23 per cent APF as a substitute for safer etching of porcelain surfaces bonded to composite. Nelson and Barghi (1989) found that the bond strength of resin bonded to porcelain etched with 1.23 per cent APF for ten minutes is equivalent to
that etched with ten per cent hydrofluoric acid for one minute. Etching with APF for longer than ten minutes significantly reduced the bond strength. Since several authors have found that optimal etching time with ten per cent hydrofluoric acid is 2.5 minutes, such a procedure should provide an adequate, although not optimal result.

Although very little has appeared in the literature regarding porcelain repair, most manufacturers now include porcelain etchant, silane coupling agent and a composite resin system. The results of porcelain repairs are short-term, yet they are often indicated rather than replacing fractured veneers which may be otherwise performing well.

The long term performance of porcelain veneers is yet to be determined. However, a four-year study by Reid et al (1988) showed excellent retention of these restorations. In addition, gingival health was not significantly altered in those areas in close proximity to the veneers when compared with other areas of the mouth, provided all appropriate measures to prevent compromised gingival health were observed. In addition, Jordan et al (1989) concluded from a four year recall evaluation of labial porcelain veneers that they provide a reliable and effective long-term procedure for conservative treatment of discoloured or malaligned anterior teeth.
Cast ceramic materials may also be used in the fabrication of veneers. The method of construction is the same as that discussed previously relating to full crowns, as are the features and requirements of veneer principles employed when using other materials. Castable ceramic (Dicor*) and apatite (CeraPearl**) materials are prepared from wax patterns and the veneers produced in the usual lost-wax method. The crystallised CeraPearl and cerammed Dicor veneers are individually characterised by a resin system and ceramic system respectively. The resin characterisation transmits the colour from beneath the hydroxyapatite crystals, with a degree of surface staining also possible. The ceramic characterisation used with Dicor restorations is similar to conventional surface shading and firing techniques. Etching of the internal surfaces is carried out using different materials. A hydrochloric acid solution is used in the CeraPearl system which selectively erodes the glassy matrix whilst leaving the inert hydroxyapatite crystals intact. Consequently, mechanical retention is achieved by a series of tags. Dicor veneers may be etched with either 10 per cent aluminium difluoride or 10 per cent ammonium, to achieve a similar result. They are then luted in the

* Dentsply International Inc., York, PA, USA.
**Hobo/Kyocera Bioceramics, Japan.
same manner as porcelain veneers (Hobo and Iwata, 1985a,b; Garber et al, 1988).

One of the major advantages of cast ceramic materials is their translucency which provides a very natural-looking restoration. As a result, they possess low masking power which renders them unsuitable for use with severely discoloured dentitions and single teeth. However, mild discolorations may be treated with these materials and a highly acceptable result obtained.
SUMMARY AND CONCLUSIONS.

Successful treatment of intrinsically discoloured teeth has been desired and pursued by dentists and their patients for many years. Only recently have the technological advances and control of dental disease allowed the widespread application of the various treatment alternatives (Faunce, 1987).

Intrinsic discoloration of anterior teeth has many causes, yet the common requirement is the need to mask or eliminate stained tooth structure and provide an acceptable restoration, or both. However, despite the common aim, an accurate diagnosis is the ideal, since this may significantly influence the treatment alternatives. In addition, proper diagnosis may also alert the practitioner to an undiagnosed systemic disorder which may be manifest by discoloured teeth. Proper diagnosis is also vital if an appropriate treatment plan is to be formulated. This is particularly relevant in cases of defective tooth development such as amelogenesis and dentinogenesis imperfecta. For example, the poor quality and frequent loss of enamel precludes the use of bonding procedures in the treatment of such conditions, for which full coverage is usually the only viable treatment option.
Aesthetically acceptable treatment requires a sound knowledge of colour science and its application to dental materials, as well as familiarity with the wide range of materials themselves. The diversity of the treatment of tooth discoloration requires a thorough understanding of tooth development, eruption and composition, dental polymers including acrylic and composite resins, bonding mechanisms including dentine and enamel bonding, ceramic systems, and bleaching agents and their combined effects upon dental and oral tissues. Understanding of these vital aspects provides an insight into the efficacies of each treatment regime to allow for a reasonable treatment plan and prognosis.

The need for a sound knowledge of the many materials available for use in this field is exemplified in the use of bleaching materials. The discovery of external root resorption following non-vital bleaching has led to a more cautious approach to this form of treatment. The premise that hydrogen peroxide is the caustic agent responsible has led to several authors stating that the use of sodium perborate and water produces an acceptable result in most cases, thereby eliminating the need for hydrogen peroxide.

The restoration of discoloured anterior teeth revolves primarily around the use of materials which
approach the optical properties of tooth structure. Materials such as dental porcelain, composite and acrylic resins and castable ceramics have all been used with varying degrees of success, with both full or partial coverage. Since the ideal restorative material does not yet exist, the advantages of each alternative must be evaluated on a case-by-case basis. Thus, the decision of which method to use is based upon the requirements of the case, and the material which best satisfies those requirements.

It is well accepted that considerable overlap exists in the indications and contraindications of several materials, particularly in the field of veneers. Other than the differences in properties, the subjective nature of aesthetic treatment means that patient considerations are perhaps more relevant here than in any other area of dentistry in determining the treatment of choice. For example, the choice between microfilled and hybrid composite resins may see one patient prefer to sacrifice aesthetics for strength and improved prognosis, whereas another may prefer maximum aesthetic benefits and a more short-term restoration. Financial considerations are also a frequent limitation.

The diagnostic criteria of lipline, occlusion, colour and optical properties, durability and surface texture are all relevant, especially with respect to dental resins and ceramics. In addition, the choice
between direct and indirect fabrication is a consideration if composite resin or porcelain veneers are indicated. Perhaps indirect resin veneers are the least desirable of these restorations for the following reasons. The two bonding interfaces involved with the resin bonding medium are the inner surface of the processed composite veneer and the etched enamel. The former is the weaker of the two, clinically seen from the failure site of such restorations. The bonding mechanism that occurs at the veneer interface involves a combination of chemical adhesion and micro-mechanical retention. Due to the processing of indirect composite resin veneers, the degree of polymerisation is significantly greater than that obtained by light alone. As a result, the potential for establishing strong chemical bonds between the veneer and luting agent is greatly diminished (Roulet, 1987). Therefore, much of the bonding that occurs is micro-mechanical in nature, which increases if the inner veneer surface is roughened prior to bonding. Thus, a luting agent which thoroughly wets the veneer surface is vital. Conversely, many authors support the use of porcelain veneers, with significantly favourable recall studies currently being published (Jordan et al, 1989).

The field of aesthetic dental materials is constantly being updated, although a breakthrough in the attempt to find the ideal restorative material does
not appear to be imminent. Variations of accepted materials such as Isosit* are available. This resin-based restorative was introduced in the late 1970's and possessed superior physical properties compared with composites available at the time. It is marketed as an indirect veneering resin, yet the problems pertaining to indirect resin veneers persist. Rucker et al (1989) found that due to insufficient resistance to fracture, this system is inferior to the porcelain veneer systems.

The translucency of castable ceramics provides an extremely aesthetic and lifelike restoration, yet restricts their use as veneers to only slightly discoloured teeth or dentitions. All ceramics are brittle and can be quite abrasive to opposing natural teeth. Thus, although an increase in fracture toughness is desirable, so is a decrease in the extent of friction produced during function. Precious metals alleviate this problem to an extent due to the lubricating effect of the metal atoms which is in contrast to the covalently bonded ceramics. This concept lends support to the use of metal-ceramic restorations.

The constant comparison of methods available for most aspects of dental treatment are both inevitable and desirable. This provides the profession with a

* Vivadent, Schann, Liechtenstein.
means by which informed decisions can be made. From the research and literature available at this time, it can be stated that although no definitive or ideal treatment of intrinsically discoloured teeth exists, there are a variety of techniques, which when utilised in the correct situation will provide a successful medium to long-term result.
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