THE MARGINAL ADAPTATION OF 3 CERAMIC VENEER TECHNIQUES: AN *IN-VITRO* STUDY

Ching Chiat Lim

BDS (Singapore)

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is dedicated to

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ABSTRACT

The inability of a restoration to form a complete marginal seal around a cavity, resulting in the eventual failure of the restoration, has long been the Achilles' heel of dentistry. Although the development of dentine bonding agents promise some light at the end of the tunnel, the clinical observation is still in its infancy. None of the restorative materials available at present truly bonds or seals the tooth-restoration interface. Therefore, it is important to minimize the marginal gaps which exist at the tooth-restoration interface. The presence of marginal gaps usually leads to microleakage and recurrent caries. This may in turn necessitate the replacement of the restoration.

Besides the continuous research in adhesive dentistry, the dental profession has also entered an era of "cosmetic" dentistry. This is to meet the demands of patients for more lasting, functional and aesthetic restorations. Amongst the wide array of materials, techniques and options available, etched porcelain laminate veneers have received substantial attention.

Porcelain veneers were first used to mask unaesthetic teeth of actors and actresses in Hollywood by Pincus in the 1920s. The technique was modified sixty years later by Horn and Calamia in 1982 by the application of the "acid-etch" technique to porcelain veneers for aesthetic modification of teeth. The success that etched porcelain veneers enjoy today can be attributed to three main factors: the acid etch technique, the improvement of the porcelain material and the composite resin luting medium.

The aim of this thesis is to present the current materials and systems available for veneer fabrications, with particular attention paid to the conventional refractory die technique, the castable glass technique and the computer aided design-computer aided manufacture (CAD/CAM) techniques. The marginal adaptation of veneers fabricated by these three different techniques are compared. The relationship of microleakage and marginal adaptation of veneers fabricated by these three techniques will also be investigated.

CHAPTER 1 REVIEW OF LITERATURE

1.1 Development of Dental Ceramics

1.1.1 History of ceramics

The term "Ceramic" is a derivative of the Greek word *Keramos*, which means pottery (Jones, 1985). It can be defined as a combination of one or more metals with a non-metallic element, usually oxygen. This combination serves as a matrix with small metal atoms or semi-metal atoms, such as silicon, positioning themselves in between the oxygen atoms (Gilman, 1967).

Simple crude applications of mud and clay were first documented 30,000 years ago, while the discovery of crude domestic pots dated as far back as 6000 to 7000 years ago (Jones, 1985). Tracing the history of ceramics is, therefore, like tracing the history of civilisation. The study and research of ceramics is one of the most extensive and oldest of the arts. This unique group of materials has withstood the test of time because it is resistant to corrosion, abrasion and dissolution, even in strong acids. The widespread use of ceramics in industries began in the 1950s. Nowadays, some ceramics are used as electrical insulators in car engines. These, in particular, require ceramic parts that are resistant to high temperatures. Other high strength ceramics are found in a wide variety of products ranging from cookware to missile re-entry cone heads.

The three basic types of ceramic materials which have been developed over the years are earthenware, stoneware and porcelain. Earthenware has a low firing temperature and is relatively porous. Stoneware, which was fabricated during the Han Dynasty around 100 B.C. (Sproull, 1977) was obtained by melting clay at high temperatures until it was no longer porous. It is stronger and more impervious to water than earthenware. Porcelain was developed in King-tetching in China in about 1000 A.D. It was obtained by fluxing white china clay with "Chine stone" which produced a white translucent stoneware (Jones, 1985). Porcelain is the finest form of ceramics in use today.

The introduction of China porcelain to Europe by Marco Polo's experience in China led to the awareness of true porcelain beauty. However, attempts by John Dwight from England and Meissen from Germany to imitate Chinese porcelain in the 17th century were unsuccessful. The secret of manufacturing translucent China porcelain was only learnt by a

Jesuit father named d'Entrecolles in 1717 (Jones, 1985). Subsequently, porcelain factories were founded throughout Europe, many of which are still in operation today.

All ceramic materials, whether earthenware, stoneware or porcelain are essentially made up of feldspar, quartz and kaolin (Craig, 1985). They only differ in firing procedures, purity and proportion of the raw materials. Ceramic has high compressive strength, low tensile strength and rigid handling characteristics (Sproull, 1977). It is a material which does not break down when exposed to a wide variety of destructive elements such as heat and chemical attack (Gilman, 1967). It can also be coloured and cleaned easily (Sproull, 1977). It is, therefore, not surprising that porcelain is now in widespread use as a dental restorative material.

1.1.2 History of dental porcelain

Dental porcelain is essentially a glass prepared from feldspar of high purity (Combe, 1986). The use of porcelain in dentistry was first suggested in 1728 by Pierre Fauchard. He described the application of jeweller's enamel to thin gold plated artificial teeth to improve aesthetics (Woodforde, 1968).

Before porcelain was used as a dental restorative material, an edentulous space was obliterated with pebbles, wood, ivory, animal and human teeth which were carved to fit or bound in place with sinew, thread or gold (Sproull, 1977). The unhygienic, appalling materials and the poor fit of the complete and partial dentures led to experiments with porcelain.

In 1774, a French apothecary, named Alexis Duchateau, became the originator of the first porcelain paste used for denture work (Woodforde, 1968). However, problems with controlling the firing contraction of porcelain led him to seek the help of a dentist, Nicholas Dubois de Chemant. He overcame the problem by adding pipe clay and colouring earths. He also baked the porcelain at lower temperatures. Duchateau retired in 1776 after numerous complaints from dissatisfied patients. Meanwhile, Chemant persevered and guarded the secret of decreasing porcelain shrinkage. He was granted an inventor patent by King Louis XVI (Jones, 1985). He moved to London in 1792, gained exclusive rights for 14 years to his porcelain paste dentures and obtained porcelain powder from the Wedgewood factory (Woodforde, 1968).

Porcelain denture teeth

The first single porcelain teeth, also known as bean teeth, were introduced by Guiseppangelo Fonzi, an Italian dentist in 1808 (Woodforde, 1968). These teeth never met with great approval due to their brittleness and opacity. It was only in 1845 that White, using the formula developed by Samuel Stockton of Philadelphia, successfully placed the porcelain tooth on a commercial basis. Together with the advent of vulcanite rubber during that time, dentures for the masses became possible (Jones, 1985).

Porcelain inlays and crowns

The first successful fused porcelain inlays and crowns were made in 1886 by C.H. Land of Detroit. In 1889 he obtained the patent for burnishing platinum foil as a matrix for construction of porcelain jacket crowns (Jones, 1985). High fusing porcelains were developed in Europe in the mid 1920s, followed by the technique of building porcelain with a brush pioneered by Jan Adriaansen of Amsterdam (McLean, 1979).

Metal ceramic crowns and bridges

In 1956, Brecker experimented with porcelain fused to certain gold alloys to form crowns and bridges. However, it was only in 1962 when M Weinstein, S Katz and A B Weinstein filed their first patent on the use of gold alloys for porcelain bonding that the universal use of metal-ceramics became possible (McLean, 1979).

Aluminous porcelain

The most important development in dental ceramics since de Chemant was the dispersion strengthening of porcelain by the incorporation of crystalline alumina as the reinforcing component within a borosilicate feldspathic glass matrix for crowns (McLean and Hughes, 1965). In 1976, aluminous porcelain was fused onto a tin oxide coated platinum matrix to produce platinum bonded crowns. Examples of aluminous porcelain cores available are Hi-Ceram®[1] and the slip cast alumina ceramic In-Ceram®[1]. To overcome the problem of firing shrinkage in conventional aluminous porcelain jacket crowns (Southan and Jorgensen, 1972), a shrink free magnesium aluminate spinel crystal injection moulded core material was

[1] Vita Zahnfabrik, Bad Sackingen, Germany.

developed (Sozio and Riley, 1983). It was marketed as Cerestore™[2] , which has now been reintroduced as Alceram[3] (Piddock and Qualtrough, 1990).

Castable ceramics

The first casting of molten porcelain into a refractory mould to make inlays and crowns was recorded in the 1920s (Wain, 1923) while the method for casting porcelain onto metal to make post crowns was described 12 years later (Fenn, 1932). In 1968, MacCulloch recognised the potential use of glass ceramics in dentistry as he found that the glass could be heat treated to produce crystallization, increasing the strength of the ceramics by 100% (MacCulloch, 1968). In 1972, a translucent and mechanically machinable material containing tetrasilicic fluormica crystals was pursued by Grossman for use in decorative work (Grossman, 1972). The machinable glass ceramic, suggested by Peter Adair for use in dentistry in 1977 (Grossman, 1983) was later used in the CAD/CAM systems for producing chairside inlays and veneers in the 1980s. In 1984, Corning glass Company and Dentsply Company eventually introduced the commercial glass ceramic, DICOR®[4] and a system for casting crowns, veneers, inlays and onlays. Another castable material, Cerapearl®[5], was also introduced in 1985. This castable apatite ceramic involves the process of converting calcium phosphate glass into a partially crystalline apatite glass ceramic (Hobo and Iwata, 1985a).

Other areas in the development of ceramics include high expansion magnesia core glass ceramic (O'Brien, 1984) and high temperature pressing of leucite-reinforced glass ceramic, IPS Empress®[6] (Reeve, 1991).

Machinable ceramics

The first commercially available CAD/CAM CEREC®[7] inlays and veneers were generated from a block of porcelain in 1985 (Mormann et al., 1989).

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[2] Johnson & Johnson, East Windsor, NJ, USA.
[3] Innotek Dental Corp., Lakewood, CO, USA.
[4] Dentsply International, York, PA, USA.
[5] Kyocera Corporation, Kyoyo, Japan.
[6] Ivoclar AG, Schaan, Liechtenstein.
[7] Siemens Dental Corp., Benshiem, Germany.

1.1.3 The Development of Ceramic Veneers

Ceramic veneers can be used to mask hypoplastic defects, fluorosis or tetracycline staining. They can also be used to close diastemas, correct labial irregularities, repair fractured teeth and fractured porcelain facings of metal ceramic restorations (Clyde and Gilmour, 1988). The conservative nature of the technique has significantly reduced pulpal and periodontal trauma often associated with the intra-crevicular crown margin placement procedures (Friedman, 1991).

The first ceramic veneers were placed on patients 60 years ago when a Californian dentist, C. L. Pincus attached thin facings of air-fired porcelain to sound teeth with adhesive denture powder to temporarily mask the unaesthetic teeth of Hollywood actors and actresses while they were before cameras. These facings provided the alternative to full crowns for the movie stars who only needed to change their smiles and appearances temporarily (Pincus, 1937).

It is not uncommon to encounter patients who have unaesthetic teeth. The causes are numerous and may affect the patients' well being and self-esteem. How well one looks is often a contributory factor to success or failure in life in the highly competitive society we now live in.

The discovery of the acid etch technique, composite luting resin, and silane coupling agents have contributed to the success ceramic veneers enjoy today. The problems of acrylic and composite resin as a veneering material have also encouraged the use of ceramic veneers.

The treatment options for intrinsic staining, enamel hypoplasticity, and anatomically malformed anterior teeth have included vital or non-vital bleaching, acrylic laminate veneers, direct or indirect composite veneers, or crowns (Calamia, 1983; Boksman et al., 1985). However, problems such as free radicals released by hydrogen peroxide used in bleaching have been associated with external root resorption (Rotstein et al., 1992), cellular changes to membranes and tissues, aging and even cancer (Powell and Bales, 1991).

With the introduction of acrylic resins in the 1940s, there was a decline in the development and the use of dental porcelains. However, disadvantages such as a high coefficient of thermal expansion, polymerization shrinkage, colour instability, poor abrasion resistance and a relatively low modulus of elasticity rendered these acrylic materials unsuitable for tooth restorations or crown and bridge prostheses (Jones, 1985). The lack of adhesion of acrylic

to tooth structure has also led to the development of the acid etch technique for enamel (Buonocore, 1955).

There are several techniques of acrylic veneer fabrication. One involves the construction of highly cross-linked, heat and pressure cured polymethylmethacrylate resins on study casts, another requires the modification of acrylic denture teeth by grinding them hollow to a thickness of about 0.5 millimetre (Faunce and Myers, 1976; Chalkley, 1980). The third technique utilizes preformed veneers of about 0.4 millimetre thickness adapted either directly on the teeth or indirectly on a stone model (Mouradian et al., 1976; Heyde and Cammarato, 1981). These veneers were then bonded on acid-etched enamel with autopolymerized or ultra-violet light cured resin. In 1979, Faunce patented the first commercially produced prefabricated acrylic veneers[8] . These veneers were heat treated directly against the replicated labial surfaces of a stone model under pressure at 300°F for five minutes. Unfortunately, the fit of the veneers was not ideal and the weak bond strength between the composite and the acrylic caused debonding or fracture of the veneers. The loss of surface lustre, marginal leakage and staining of the restoration also resulted in an unacceptable appearance (Coyne and Wilson, 1988; Calamia 1983).

With the introduction of the acid etch technique and later, the development of Bis-GMA composite resin material by Bowen in 1958, dentistry entered a new era. The first direct bonding of composite resin to modify discoloured or malformed teeth was achieved with large particle 10-70 micrometre traditional composite resins. However, within 18-24 months after placement, the veneers lost their surface lustre, appeared mottled and discoloured due to water sorption and surface degradation (Coyne and Wilson, 1988). With the development of light cured microfilled composite resins, several direct techniques were developed. Semi-transparent silicone impressions (Fayyard and Wilson, 1987) and transparent acrylic resin matrices were used to replicate the facial surfaces of teeth to allow adequate reproduction of the original contour, shape and surface texture of the teeth by the composite resins (Baratieri et al., 1992).

The inherent polymerization shrinkage property of the composite resin material increases with the bulk of the resin and renders the restoration liable to higher contraction stresses at the margins. This may in turn cause marginal opening, susceptiblility to microleakage and subsequent staining and caries (Lutz et al., 1986). Unlike direct composite veneers, the amount of composite resin used in cementing porcelain veneers is relatively thin, around 40-50 micrometres (McLaughlin, 1987). However, contrary to the assumption that polymerization shrinkage and stress would be reduced when the layer of composite resin is

[8] Mastique Laminate Veneer System, L.D. Caulk Co., Delaware, USA.

thin, Feilzer et al. (1989) found that the polymerization shrinkage and stress in a thin layer of resin is approximatey three times that found in a composite restoration. Variable thicknesses of composite resin beneath a laminate have also been observed to shrink differentially as it sets, thereby stressing the laminate (Hunt , 1986).

Due to the time consuming, highly artistic and technically demanding nature of the direct composite resin method (Heymann, 1987), several indirect laboratory processed composite systems which involve light, heat or vacuum curing have been developed. These systems save clinical chair time and they provide aesthetic results. They can also be contoured and polished better (Gross, 1985). However, the indirect composite veneer technique also has a few limitations. The bond strength between the luting cement and the resin veneer is less than that of the etched porcelain veneer and the resin cement (Heymann, 1987). Two appointments, plus the laboratory fee may also make the restoration more costly than the direct technique.

The concept of bonding acid etched porcelain veneers to etched enamel was introduced in 1982 by Horn and Calamia. Etching porcelain with a hydrofluoric acid substitute, Stripit[9], for 20 minutes provided a mechanical bond and resulted in good bond strengths to composite resin (Simonsen and Calamia, 1983). This bond strength was further increased when the etched veneer was treated with an organo-functional silane coupling agent (Calamia and Simonsen, 1984; Nicholls, 1988). The shear bond strength of etched and silane treated porcelain has been reported to be as high as 24 MPa (Hsu et al., 1985) and 22.4 MPa (Ibsen et al., 1987) respectively.

The porcelain veneers can be fabricated in the laboratory using either the platinum foil technique or the refractory die technique (Calamia, 1985). Other methods such as the lost wax technique utilizing castable glass ceramics (DICOR®) or the leucite-reinforced ceramic press system (IPS Empress®) and the CAD/CAM system (CEREC, Siemens) can also be used to fabricate veneers.

[9] J-Pin Co., Stanton, California, USA.

1.2 What is a Porcelain Laminate Veneer ?

Introduction

A porcelain veneer is usually a thin facing of about 0.5-0.7 millimetre thickness (Millar, 1987; Faunce, 1987) covering the labial aspects of anterior teeth and the buccal aspects of some bicuspid teeth. The veneer is attached to the enamel surface by a combination of mechanical and chemical bonding. The mechanical attachment is achieved by etching the enamel and the porcelain. The composite is then allowed to form a strong micromechanical bond similar to that achieved with enamel (Clyde and Gilmour, 1988) while an additional chemical attachment to the porcelain interface is accomplished by silane bonding (Quinn et al., 1986). Studies have shown that etching the porcelain surface was of greater importance in overall bond strength than using a silane coupling agent alone (Calamia and Simonsen, 1984). The veneer is then cemented with autopolymerized, light cured or dual-cured composite resins to the enamel surface.

1.2.1 Indications for porcelain laminate veneers

1. Management of non carious surface defects such as (Boksman et al., 1985):
   a. Localized enamel malformations.
   b. Enamel hypocalcification.
   c. Enamel hypoplasia.

2. Masking of discolouration resulting from (Horn, 1983):
   a. Fluorosis.
   b. Non-vitality.
   c. Tetracycline staining.
   d. Root filled teeth where aesthetic improvement is required but where it is undesirable to place a post core.

3. Repair of structural defects such as (Horn, 1983):
   a. Fractured incisal edges.
   b. Mild malalignment of teeth.
   c. Closure of diastemas.
   d. Peg shaped laterals.

4. As an intermediate restoration for the correction of cosmetic or minor functional needs in children's teeth e.g. spacings between teeth, rotated or lingually inclined incisors. Crown preparations on adolescent teeth are difficult due to the risk of infringement on the large immature pulp by too deep a shoulder preparation (McLean, 1991).

5. To repair the fractured porcelain facing of bridgework (Millar, 1987).

Porcelain veneers have also been used as "orthodontic retainers" to close post-orthodontic diastemas (Hunt, 1985; Reid and Stirrups, 1987) and to treat eroded teeth (Reid et al., 1991).

Applications of this new concept are extensive, but care must be taken to evaluate the limits of this technique with adequate long term clinical evaluation. Clinical observations have also confirmed that etched porcelain veneers are ideally suitable for mandibular incisors if adequate interincisal space exists and the correct tooth preparation design chosen for the required occlusion (Freedman, 1989). This is because typical subgingival full coverage procedures on mandibular incisors are difficult and usually result in an adverse periodontal response (Friedman, 1987).

1.2.2 Criteria for case selection

Patients who are selected for porcelain veneers, like any other restorative work, should have good oral hygiene, healthy gingival tissue and no occlusal disharmony (Millar 1987; Clyde and Gilmour 1988).

The criteria for case selection can be enumerated as follows:

1. Static and dynamic occlusal relationship

The incisal porcelain finishing line will be determined by the contact relationships between the incisors and canine in centric occlusion and lateral excursion (Quinn et al., 1986). The margins should be placed without contact with the opposing dentition during rest position (Faunce, 1987). Edge to edge incisor relationships and occlusal interference are contraindications.

2. Periodontal and oral health status

A healthy periodontium forms a strong foundation on which all restorative work will rest. It also facilitates ease of impression taking, cementation and future maintenance.

3. Condition of tooth

a. Degree of discolouration.
b. Extent of caries, if present.
c. Extent of restoration, if present.

4. Quality of tooth

a. Amount of enamel for intraenamel preparation and effective bonding.
b. Severity of structural defects, if present.
c. Teeth with large areas of exposed dentine are unsuitable, although small areas may be treated with dentine bonding agents or glass ionmer cement.

5. Patient's motivation to maintain

A vigilant home care programme of the mouth is important to maintain the longevity of the restoration.

6. Oral habits

Tooth-to-foreign object or tooth-to-tooth habit patterns such as pencil biting or bruxism are contraindications for veneers as the shearing stress may be too great for the porcelain to withstand (Heyde and Cammarato, 1981).

1.2.3 Advantages and limitations of porcelain laminate veneer

Advantages of the porcelain laminate veneer:

The porcelain veneer is usually fabricated in the laboratory. It utilizes the ceramist's expertise in creating a realistic restoration and allows the dentist to individualize and characterize the veneers (Greggs, 1988). Compared with the preformed resin laminate veneer, the porcelain laminate veneer also has the following advantages (Horn 1983):

1. Colour stability and life like appearance.
2. Maintenance of lustre.
3. Higher resistance to abrasion.
4. Biocompatibility with gingival tissue.
5. Higher resistance to staining.
6. Increased chemical and mechanical bonding to composite resin.
7. Resistance to the deleterious effects of alcohol, medications, and other solvents.
8. Better fit can be obtained through custom fabrication.

Limitations of porcelain laminate veneer:

1. The colour of porcelain veneers fabricated by the refractory die or platinum foil technique cannot be changed after they have been completed in the laboratory should the need arise. The veneers will have to be redone or modified using coloured luting cements (Horn, 1983); although success in shade modification with luting cement is highly questionable (Ironside, 1993).

2. No reglazing or firing is possible with the refractory die or platinum foil fabricated veneers. Therefore gross changes in length, contour and contact are limited (Horn, 1983).

3. Stabilization at try-in stage is difficult as there is no tenso-frictional grip (Horn, 1983). This difficulty can however be overcome by making a definite incisal step on the labial surface of the veneer preparation (Ironside 1993).

4. Dental laboratory costs involved may make the restoration more expensive to produce and thus dearer to the patients (Horn, 1983).

5. Marginal adaptation of most veneers is about 100 micrometres. Very few with a marginal accuracy of less than 20 micrometres have been achieved (McLean, 1991).

6. Thin sections of porcelain tend to be monochromatic and lack the break up of colour present in natural teeth. If the veneer is too translucent, areas of marked discolouration may show through whereas a more opaque porcelain build up may produce a high value monochromatic veneer, lacking in translucency and dentine contrast (McLean, 1991).

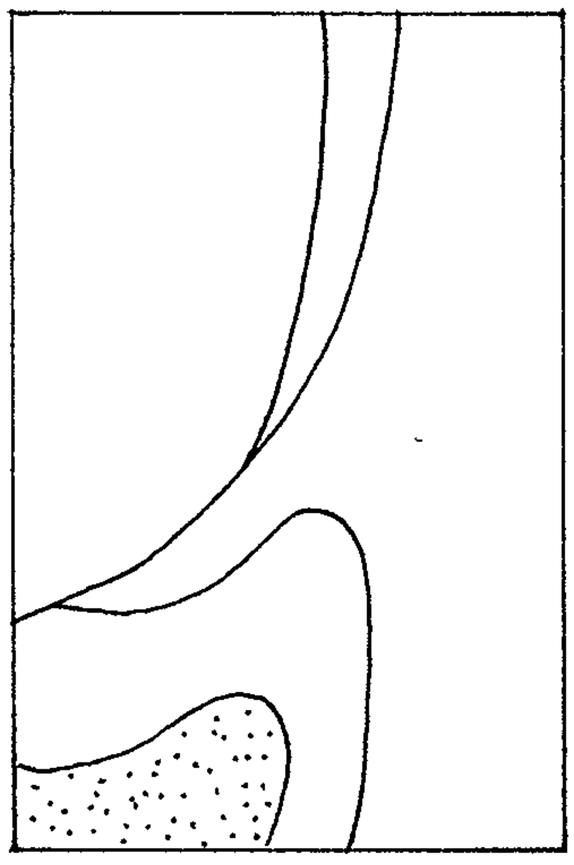
1.2.4 Tooth preparation versus non-preparation

The necessity for tooth preparation for the application of porcelain veneers is still debatable (Freedman et al., 1989). A slight modification of labial enamel to reduce bulges is usually suggested (Horn, 1983; Çalamia, 1983). Photoelastic studies of stresses on porcelain laminate preparations have also indicated that the stress of an unprepared tooth is dispersed over a larger area with greater intensity. Gingival tooth preparation is essential to control stress distribution and provide favourable periodontal health (Highton et al., 1987).

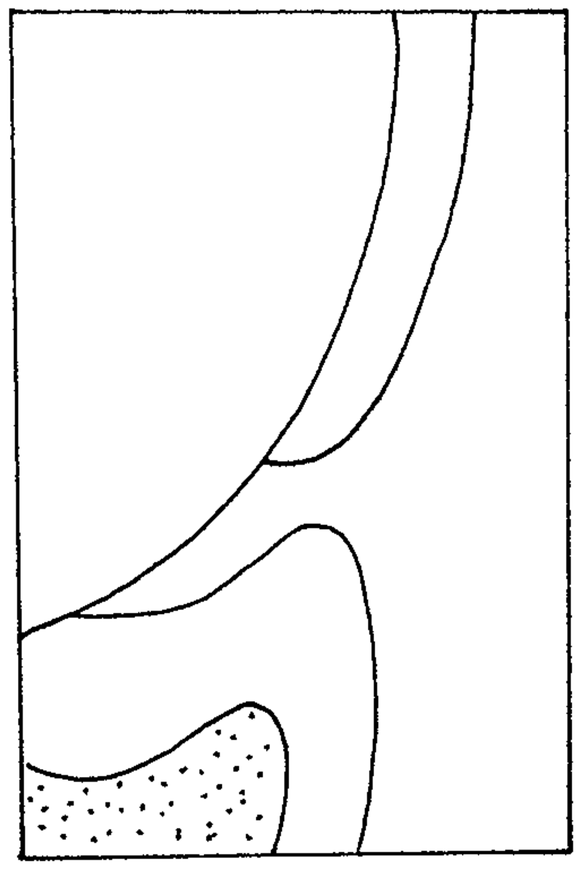
To solve the dilemma of tooth preparation for porcelain veneers, a goal has to be set. That is, to produce a veneer which will effectively correct any given aesthetic problem and also provide long term stability and no subsequent periodontal changes (Garber, 1991). It is undesirable to finish a porcelain margin in a feather thin edge (Figure 1.2.1a). Not only is it extremely difficult to fabricate porcelain with a micro thin margin without some degree of distortion associated with firing shrinkage, but fracturing of this thin margin is also likely to occur. The solution to this problem would be to fire thicker porcelain at this juncture. However, this would have an adverse effect on the periodontal health (Friedman, 1987) as a thicker porcelain margin at this juncture without any tooth preparation (Figure 1.2.1b) would be a depository area for plaque accumulation. Although it is possible to thin down the thickened porcelain-enamel junction once the veneer has been cemented, this process of recontouring is very time consuming. Also, the heat generated may cause crack formation in the porcelain and compromise the bonding between the etched porcelain and enamel. This could result in microleakage which may later present itself clinically as recurrent caries or cervical laminate fracture (Garber, 1991). The process of excessive gingival contouring of the veneer also removes the glaze which makes restoration of original smoothness very difficult. Damage to the cementum is also likely to occur.

There are other times when no tooth preparation or very minimal tooth preparation is required e.g. in very young patients, when teeth are retroclined or when sound teeth like peg shaped laterals are being built up (Clyde and Gilmour, 1988). In most cases, however, to allow for efficient, effective, and predictable placement of veneers in the mouth and efficient fabrication in the laboratory, some form of tooth preparation is necessary (Figure 1.2.1c).

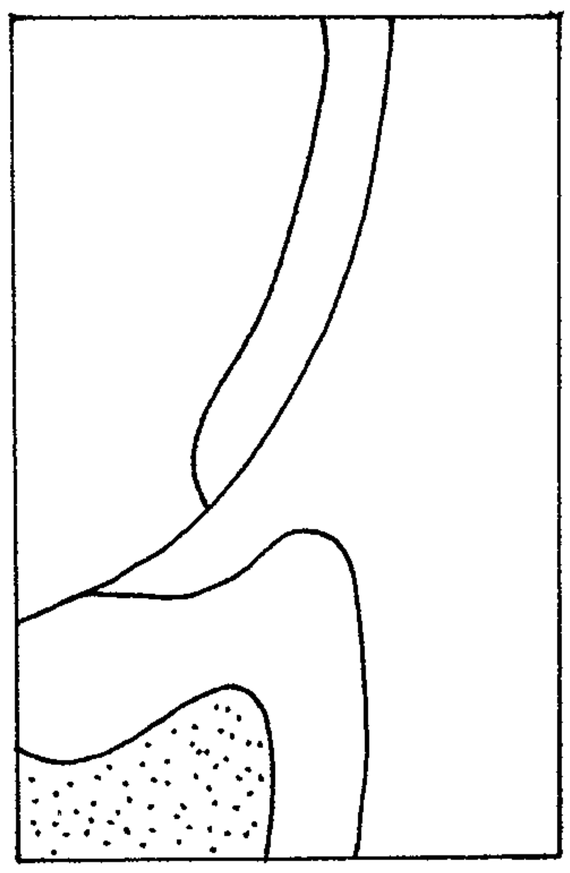
Figure 1.2.1 Profiles of porcelain veneer and tooth margins



(a)
Undesired feather edged
porcelain margin design



(b)
Undesired overcontoured
porcelain margin design



(c)
Desired end result of veneer
placement with tooth preparation

The rationale for enamel modification is based on the physical needs of the porcelain material, the biological needs of the periodontium, the technical needs of the ceramist, and the aesthetic demands of the patient. They may be categorized into (Garber, 1991):

1. Strength.
2. Contour.
3. Colour.
4. Seating.
5. Finishing.
6. Margin placement.

1. Strength

The exposure of ceramics with surface faults to water produces a stress dependent chemical reaction which reduces the strength of glass, a phenomenon known as "static fatigue" (McLean, 1988). Delayed failure may occur as Griffith flaws or cracks, inherent in ceramics, propagate (Smyth, 1977). Therefore, an increase in strength and toughness of ceramics is highly desired. This can be achieved via a number of methods such as, enamelling of metals, dispersion strengthening, crystallization of glass, chemical toughening and bonding to thin gold or platinum foil (McLean, 1991). It is with this in mind that the design of tooth preparation for porcelain veneers is considered. Ceramic needs bulk for strength, therefore adequate tooth reduction is mandatory (Wall and Cipra, 1992). Porcelain in veneers is also strengthened via its bonding to the underlying composite resin (Nathanson, 1988). Preparation also increases the surface area of enamel available for bonding by creating a grooved undulating surface which also enhances physical retention. To further enhance the cohesive bonds between the laminate and the enamel, the preparation is extended into the interproximal areas. This helps to minimize the potential displacement of the veneer labially. The extension of the margins interproximally also obscures the junction of the laminate and the aesthetically compromised tooth. The removal of the surface enamel improves the bonding efficacy as the "skin of the tooth", which is rich in fluoride (Brudevold et al .,1956), has been shown to decrease the surface free energy and wettibility of enamel, a situation conducive to lower bonding strengths (Sheykholeslam et al., 1972).

2. Contour

The contours and junction between the porcelain and the tooth should continue and blend imperceptibly (Figure 1.2.1c). This is only possible if a layer of surface enamel is removed and then subsequently replaced with an equivalent amount of porcelain. If tooth preparation is not performed, there will always be an excessive contour labially at the junction of the veneer and the tooth. Therefore, tooth preparation allows proper thickness of porcelain without increasing the labial-lingual dimension of the final restoration (Parmeijer, 1991).

3. Colour

A minimal space of about 0.5 millimetre is required for the development of the correct shade in the porcelain to effectively mask the underlying tooth staining (Plant and Thomas, 1987; Garber, 1991).

4. Seating

Tooth preparation provides a distinctive finishing margin which allows definitive placement of the veneer and intimacy of fit (Garber, 1991).

5. Finishing

Removal of excess composite resins is made easier when a definitive margin is present as it is very difficult to discern porcelain, composite and tooth structure under high speed instrumentation and water spray if the tooth is not prepared (Garber, 1991).

6. Margin Placement

Preparation of the tooth allows the placement of an intracrevicular margin when the transition between the corrective lighter-coloured porcelain and the underlying discoloured tooth is to be hidden (Garber, 1991). The technician is also able to produce a better fitting restoration with a distinct margin (Harley and Ibbetson, 1991). All of the margins should be placed without contact with the opposing dentition and at least 50% of the preparation should be in enamel (Faunce, 1987).

1.2.5 Types of tooth preparation for porcelain laminate veneers

Before tooth preparation for veneering is attempted, a clear knowledge of enamel thickness is essential as studies have shown that at least 55% of the preparation and all the margins in enamel are required to ensure long term retention and good marginal seal (Gougoulakis et al., 1991). A study of enamel thickness at gingival, middle and incisal areas of upper and lower anteriors and first premolars (Figure 1.2.2) undertaken by Crispin (1993) showed that the thickness of enamel within one tooth varies. The thickness of enamel is often less than 0.3 millimetre at a point 0.5 millimetre incisal to the cementoenamel junction (Table 1.2.1), an area where most dentists would terminate the gingival margin of a laminate veneer.

The types of tooth preparation have been categorized by the path of insertion, namely facial and gingival, with minimal or maximal tooth reduction (McLaughlin, 1986). For the sake of simplicity, tooth preparations for porcelain laminate veneer will be discussed under two main headings:

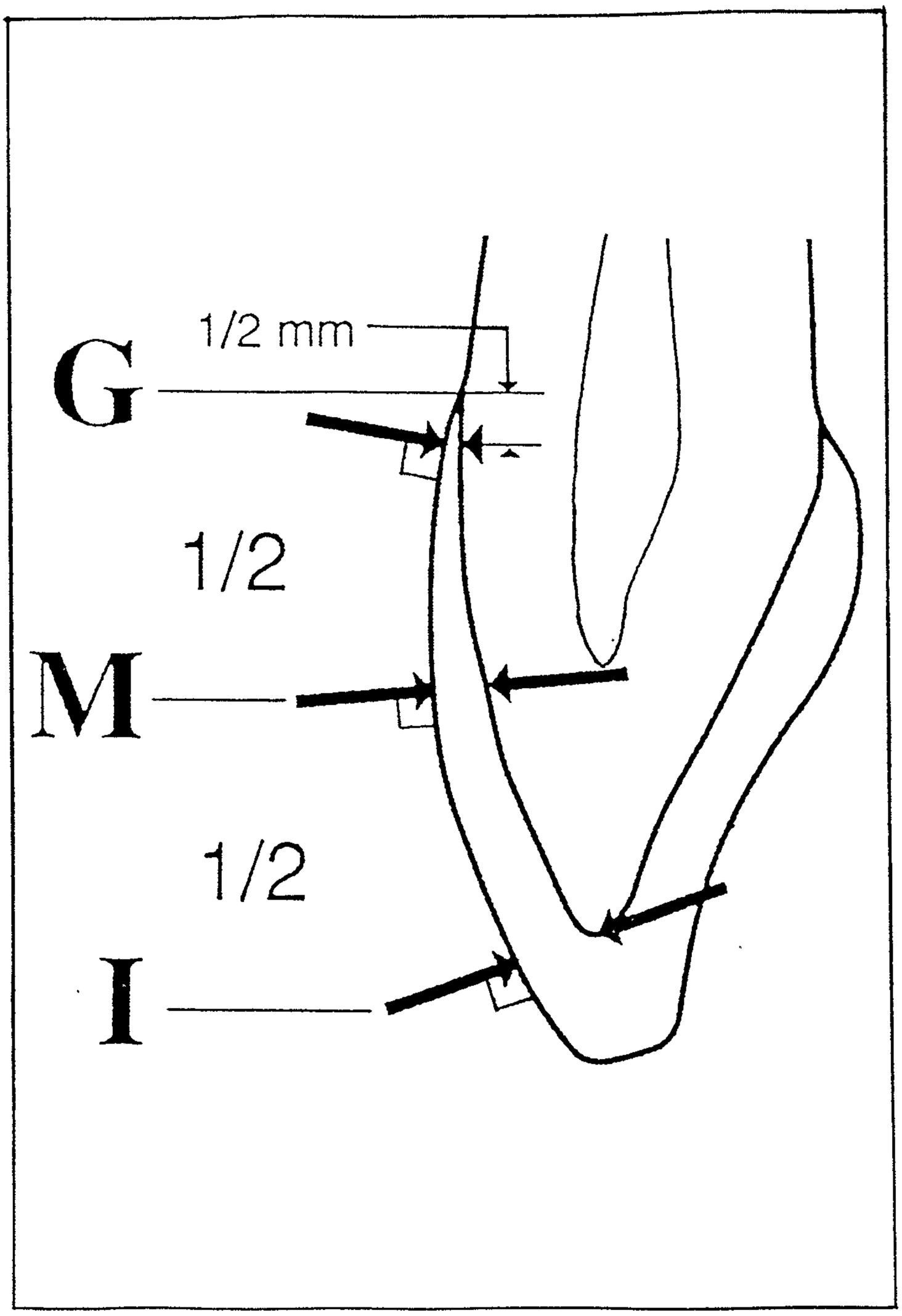
1. Tooth preparation without incisal reduction.
2. Tooth preparation with incisal reduction.

1. Tooth preparation without incisal reduction

a. "Window" preparation

The labial reduction is feathered incisally to terminate just short of the incisal edge (Figure 1.2.3a). This design has the advantage of leaving the incisal edge intact but tends to limit the aesthetic result (Harley and Ibbetson, 1991). Careful considerations must be given to the thickness of tooth structure remaining to prevent its fracture. Where incisal contacts during protrusive, latero-trusive, or lateral excursions are expected, incisal edge reduction is preferred (Harley and Ibbetson, 1991). Dynamic stress analysis and two dimensional photoelasticity were performed to relate the strength of porcelain veneers fabricated to three different designs. The results showed that the "window" preparation was the strongest compared with the "overlapped" and "feathered" designs (Hui et al., 1991).

Figure 1.2.2 Enamel thickness measurement points



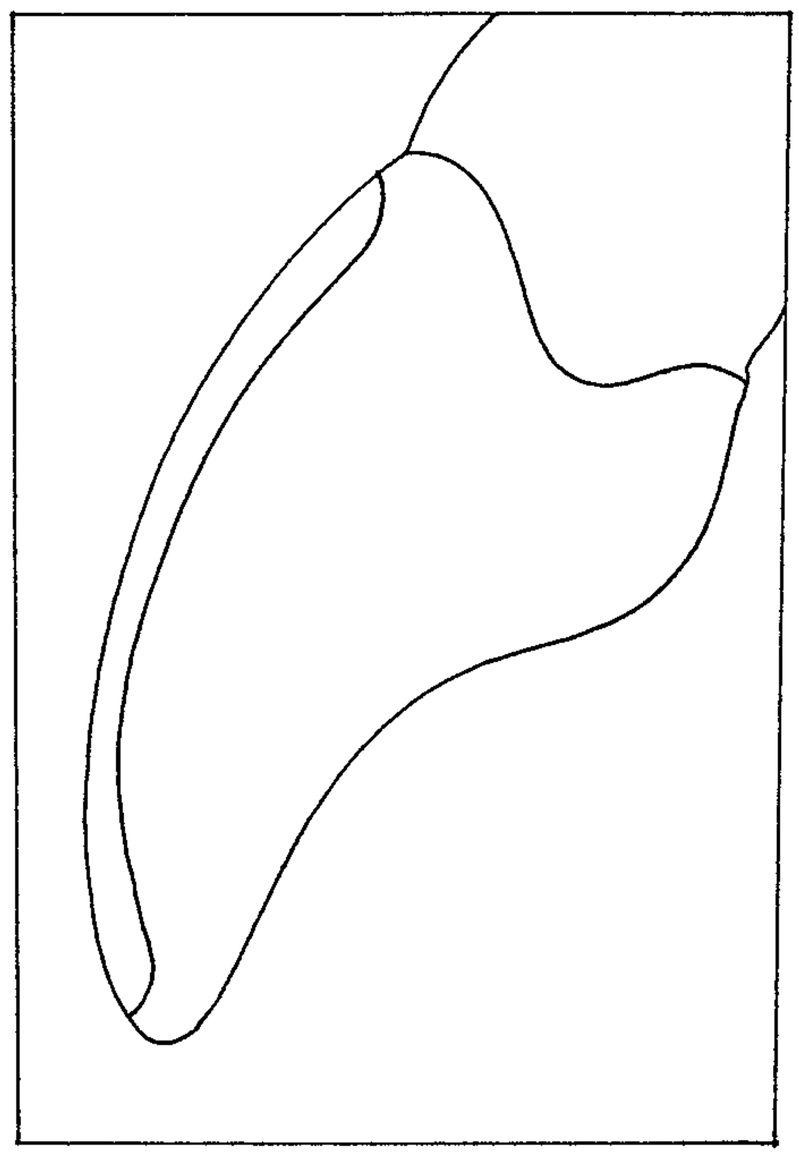
Adapted from BJ Crispin. Center for Esthetic Dentistry. UCLA .

Table 1.2.1 Thickness of enamel (Crispin, 1993)

	G(Gingival)	M(Middle)	I(Incisal)
Maxillary			
Centrals	.245±.069	.795±.115	.863±.094
Laterals	.260±.082	.920±.199	1.018±.183
Canines	.236±.090	.997±.236	1.189±.288
Bicuspids	.262±.189	1.245±.188	1.415±.176
Mandibular			
Centrals	.196±.080	.660±.143	.782±.091
Laterals	.178±.031	.579±.124	.883±.135
Canines	.235±.055	.943±.141	1.114±.180
Bicuspids	.258±.074	1.298±.207	1.400±.186

Mean enamel thickness ± standard deviation in millimetres

Figure 1.2.3 Tooth preparation without incisal reduction



(a)
"Window" Preparation

2. Tooth preparation with incisal reduction

Compulsory incisal reduction is advised for porcelain veneers placed on mandibular teeth which are in Class I or II relationship (Harley and Ibbetson, 1991).

a. The labial preparation (Harley and Ibbetson, 1991)

Also known as the feathered incisal edge, this preparation includes labial and incisal edge reduction but does not reduce the crown height (Figure 1.2.4a).

b. Labial reduction with an extra labio-incisal step (Ironside, 1993)

The design of this preparation is similar to the labial preparation plus a definite incisor step created labially without compromising the crown length. The extra step provides bulk for the porcelain material and also aids in seating of the veneers during cementation (Figure 1.2.4b).

c. Definitive incisal edge reduction (Harley and Ibbetson, 1991)

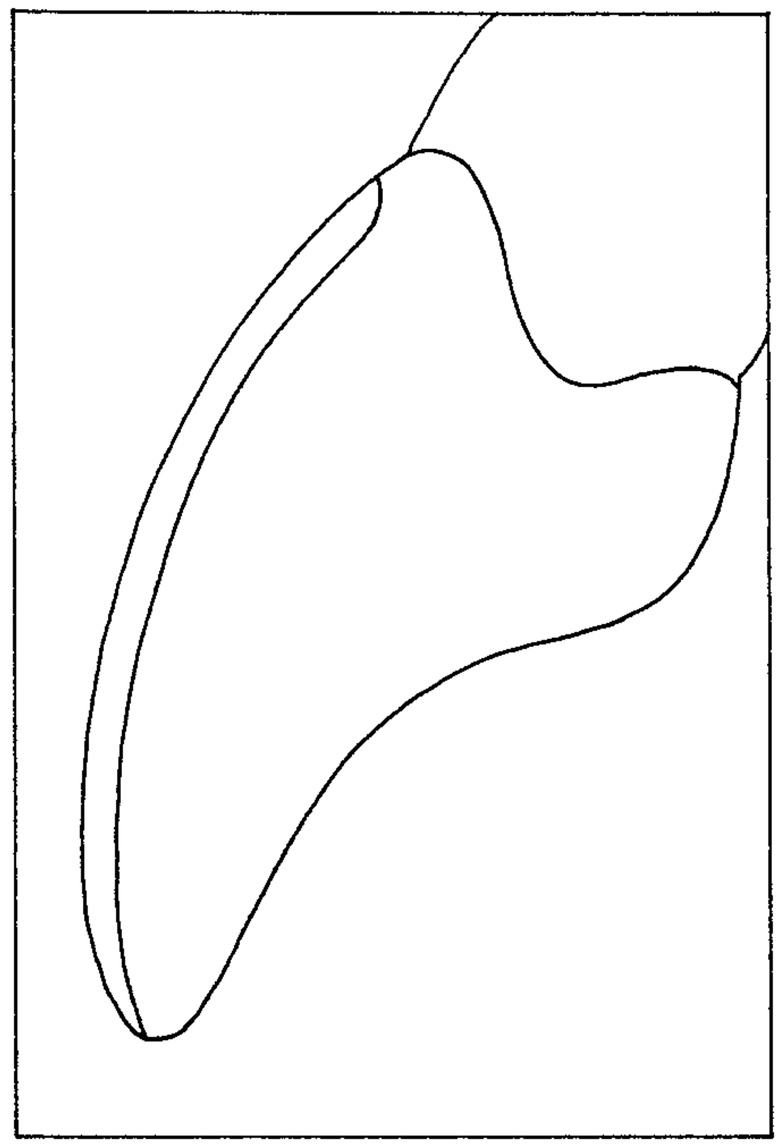
This design involves 1.5 millimetre of tooth structure removal incisally similar to the incisal reduction in crown preparation with the finishing margin terminating at a butt joint with the tooth palatally or lingually (Figure 1.2.4c).

This permits the restoration of incisal edges entirely in porcelain which allows more natural translucency (Harley and Ibbetson, 1991).

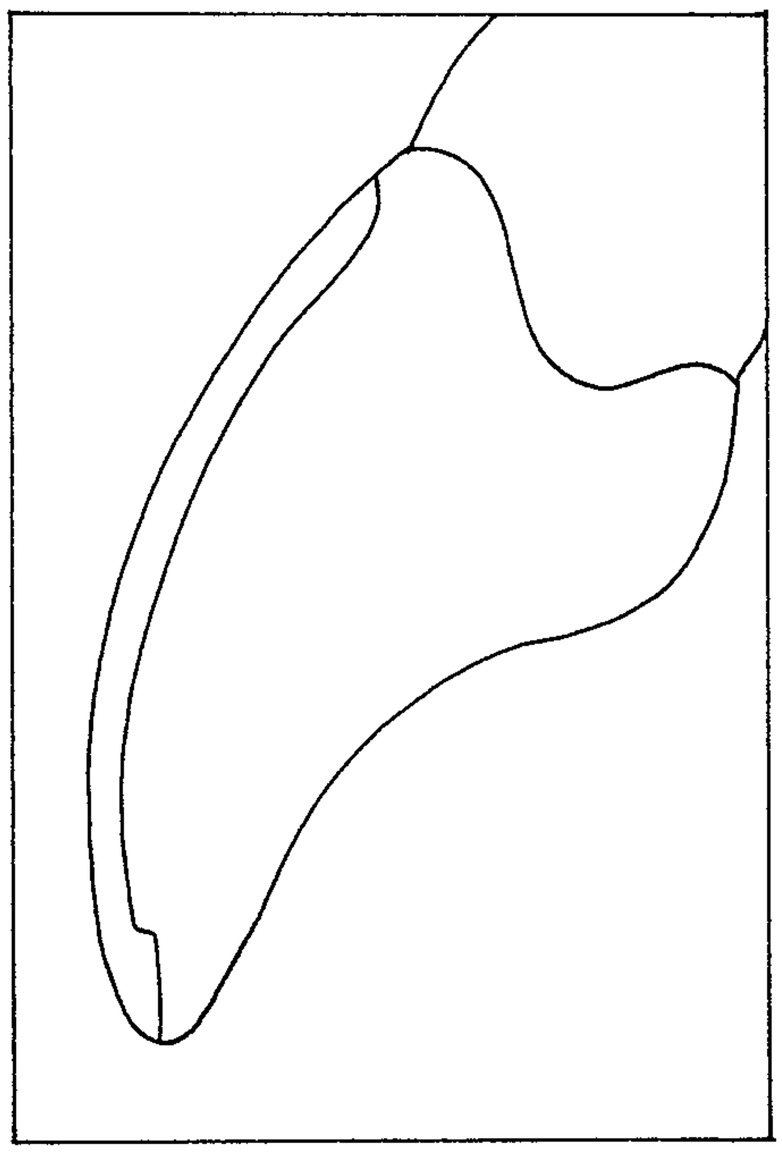
d. Overlapped incisal edge reduction (McLaughlin, 1986)

Incisal reductions of 0.75-1 millimetre (Quinn et al, 1986) and 0.5 millimetre (Calamia, 1985) have been suggested to form a slight incisal overlap. This preparation leaves some intact incisal edge with the veneer overlapping it and ends with a step palatally or lingually (figure 1.2.4d). This design is more conservative than 1.2.4c and may resist shearing forces much better (Harley and Ibbetson, 1991). It also provides more support to the overlying porcelain if enough bulk of tooth structure remains after preparation. Photoelastic studies have also shown that coverage of the incisal edge and gingival tooth preparation could be responsible for increasing the resistant surface area and lowering the concentration of stresses in the veneer (Highton et al., 1987).

Figure 1.2.4 Tooth preparation with incisal reduction

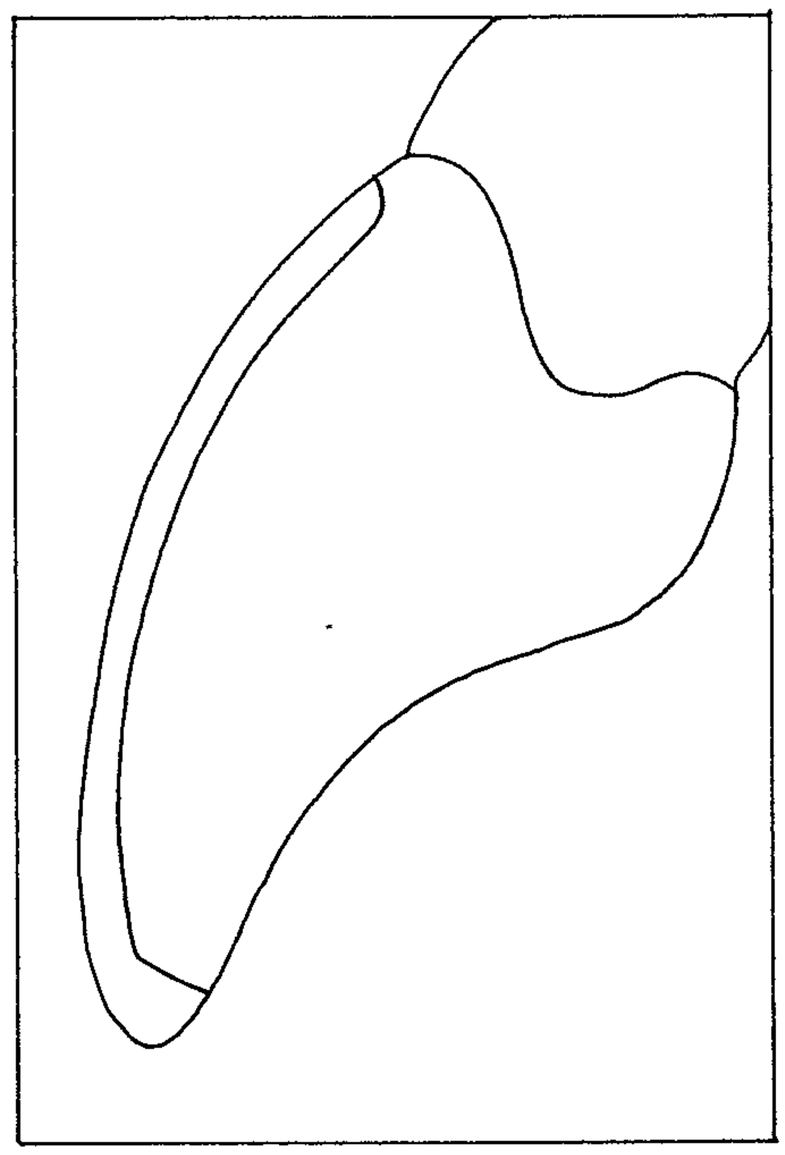


(a) Labial reduction with feathered incisal edge

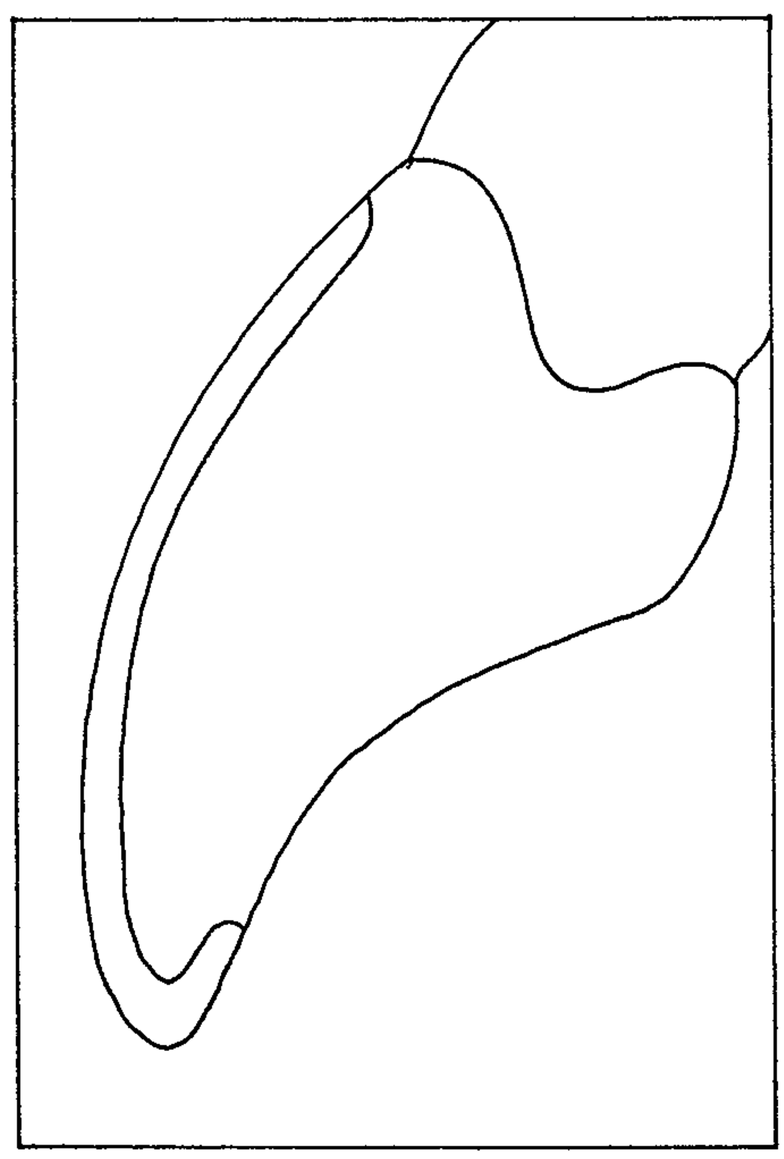


(b) Labial reduction with labio-incisal step

Figure 1.2.4 Tooth preparation with incisal reduction



(c) Definitive incisal edge and labial reduction



(d) Overlapped incisal edge with labial reduction

Labial Reduction

A number of articles regarding the amount of tooth structure to be removed have been written. Some advocate at least 0.5 millimetre or more precisely, 0.75-0.85 millimetre reduction of tooth structure (Faunce, 1987), while others, 0.5 millimetre (Calamia, 1985; Quinn and Byrne, 1986), or 0.3-0.5 millimetre (Czarkowski, 1985). Harley and Ibbetson (1991) suggested a 0.5-0.7 millimetre reduction while Quinn et al. (1986) advised a 0.5 millimetre labial and 0.75-1 millimetre incisal reduction with chamfer finishing line placed 0.5-2 millimetres supragingivally. Due to the limited amount of enamel (0.5 millimetre) present on most anterior teeth (Plant and Thomas, 1987), and often less than 0.3 millimetre at the gingival area (Crispin, 1993), a removal of not more than 0.5 mm tooth structure labially is suggested. Depth cuts are placed on the labial surface of the tooth with either a round bur of the correct size or porcelain veneer preparation and finishing bur kit[10]. The kit contains depth cutters which are 0.5 millimetre and 0.3 millimetre (LVS #1 and #2) and two grit diamonds (LVS #3 and #4) for reducing the overall labial enamel.

Proximal Reduction

The margins should extend proximally to wrap around the contact points (but not breaking them) to eliminate the porcelain margin when the tooth is viewed from an angle. Where small and sound proximal restorations are present, they should be incorporated into the preparation design. The margins of the preparation should also end beyond the restoration to rest on sound tooth structure. To preserve and promote the most ideal periodontal health, restorative efforts should be planned for the incorporation of supragingival margins (Friedman, 1987). The cervical margin of the preparation should follow the contour of the free gingival margin and should be placed at or above the free gingival crest (Friedman, 1987). Calamia advocates a slight chamfer margin which is just visible, about 0.5-1 millimetre above the cervical line of the tooth (Calamia, 1983).

After the preparation has been completed, retraction cords can be placed intra-crevicularly, and then an elastomeric impression of the preparations together with an alginate impression of the opposing arch can be taken.

[10] Komet® Laminate Veneer Sysytem Set 4151.

Rules for porcelain veneer tooth preparations :

1. Whenever a more conservative alternative is available, tooth structure should not be removed unnecessarily (McLaughlin 1986, 1988).

2. The patient must be informed when tooth preparation is to be performed (Nathanson,1986).

3. Contact areas must be preserved (McLaughlin, 1986).

4. Preparation should be kept intraenamel and should not be deeper than 0.5 millimetres from the original tooth surface (Nathanson, 1986) to prevent exposure of dentine (McLaughlin, 1988).

5. The gingival margin should be cleansable (McLaughlin, 1988).

6. The preparation should be free from any undercuts or sharp internal line angles (McLaughlin, 1988).

1.2.6 Clinical procedure for porcelain laminate veneer fabrication

The clinical procedure for porcelain laminate veneer fabrication involves the following steps:

a. Examination and treatment plan.
b. Shade selection.
c. Tooth preparation.
d. Temporization.
e. Try in of veneers.
f. Cementation of veneers.
g. Finishing of veneers.

a. Examination and treatment plan

A thorough examination of the oral environment, including the periodontal status and caries activity, should be undertaken. Patient's needs should be clearly identified and a realistic solution provided. A detailed examination of the areas enumerated in section 1.2.2 should then follow. Any parafuctional oral habits should be identified and an occlusal analysis

performed. Use of study casts, mounted on a semi-adjustable articulator, could also allow further occlusal analysis (Harley and Ibbetson, 1991).

b. Shade selection

Shade selection should be done under natural daylight prior to tooth preparation. Attention should be paid to minimize the transgression from the cervical of the tooth to the veneer. This can be achieved by developing the proper translucency in the gingival one millimeter of the porcelain laminate to obtain an optically invisible junction (Friedman, 1987). The laboratory prescription should include details like graduation of shade or any characterization (Harley and Ibbetson, 1991). The final shade of the porcelain veneer depends on multiple factors, such as the shade, opacity and thickness of the veneer, the underlying tooth colour, the thickness, shade and opacity of the luting composite, and the optical shift during polymerization of the resin. This situation makes predetermination of the final shade an educated guess, especially in the treatment of darkened teeth, such as those with tetracycline stains. One way to overcome this problem is to fabricate an extra veneer to be used for trial cementation. This trial veneer is not etched, but is lubricated with glycerine or silicone on the internal surface. The selected composite shades are placed in the veneer and seated on the unetched but lubricated tooth. By curing the resin/veneer in place and waiting for several minutes, the actual shade can be confirmed. The trial veneer can then be removed carefully and additional resin shades evaluated (Friedman, 1987). However, as the space available between the veneer and the tooth is usually 40-50 micrometres, it is quite difficult to alter the final shade of the restoration significantly with luting cement (McLaughlin, 1987). On the other hand, studies have shown that the operator has a greater shade control through the use of luting composite when the veneer is thin rather than thick (McLaughlin, 1987).

c. Tooth Preparation

Any of the tooth preparations enumerated in section 1.2.5 can be used to prepare the tooth for veneer using the platinum foil or the refractory die techniques. Other methods of veneer fabrication (such as the CAD/CAM techniques) will require slight modifications to the preparation. The preparation types only serve as a guide for the dentist. Differences in tooth position, shape and colour will dictate the type of tooth preparation to provide the most aesthetically and functionally pleasing restoration. Where old and sound composite restorations are involved as part of the preparation, the restoration can either be etched with phosphoric acid gel or hydrofluoric acid gel to create a microporous surface to which the porcelain veneer may be more reliably bonded (Jordan et al., 1989). Exposed dentine should be covered with a thin layer of dentine bonding agent, followed by elastomeric

impressions of the preparations. It is recommended that three impressions be taken when three to six veneers are involved (Sheets and Taniguchi, 1990).

d. Temporization

There is a controversy with regard to temporization in porcelain veneers. Some feel that temporization is unnecessary (Millar, 1987; Nasedkin, 1988; Nathanson, 1986) while others feel that they are a necessary, especially when extensive reduction has been performed to change the position or alter the length of the teeth (Willis, 1988; McLaughlin, 1988). In such cases, temporary coverage is needed to give the patient a "normal" appearance. A method utilizing a heat-vacuum clear vinyl template of the uncut teeth on the study model has been documented. The template is usually filled with composite or acrylic resins and seated securely over the teeth (Willis, 1988). After the margins have been polished carefully, the tooth is spot etched and the temporary veneers secured with a chemical cure or a light-cured composite luting cement. The lingual surfaces of the veneers can also be etched before cementation (Willis, 1988). Other authors have advocated the use of composite resins on unetched teeth to facilitate easy removal (Calamia, 1985; McLaughlin, 1988).

e. Veneer try-in

After the temporary veneers have been removed and the teeth cleaned, the veneers are gently seated. Trying to improve seating by increasing digital pressure may fracture the veneer. High spots, which may be preventing proper seating of the veneer, have to be removed. Once the fit has been verified, the colour of the veneer should be assessed. This can be done with a drop of water between the veneer and the tooth (Nathanson, 1986; Ironside 1993). Alternatively, different shades of resin on the fitting surface can be tried on the unetched tooth (Nathanson, 1986; Friedman 1987). When the appropriate shade has been determined, the veneer is removed from the tooth. The fitting surface and the enamel are cleaned with saturated acetone or alcohol to remove the composite. If the veneer has not been etched in the laboratory, it is now etched with 5% hydrofluoric acid for about a minute (depending on the manufacturer's instructions), then washed and dried. To avoid oil or water contamination from compressed air, a small hair dryer, with an attachment to limit the warm air flow, is recommended for drying the laminate (Horn, 1983). Great care must be taken when handling hydrofluoric acid, as it is very corrosive. After etching the porcelain, a silane coupling agent compatible with the composite luting agent to be used is applied to the fitting surface of the veneer, according to the manufacturer's instructions.

f. Cementation

A rubber dam is applied and everted before cementation. Each preparation can also be ligated with a floss to enhance security and isolation of the rubber dam. The labial enamel surfaces are cleaned with a glycerine and fluoride free pumice slurry. The interproximal areas are cleaned with fine abrasive strips. Where more than one veneer is being cemented, each should be placed as a separate procedure to allow adequate control of the operating field. The isolation of individual teeth is provided by the placement of clear celluloid strips in the approximal areas. These should remain in place during the cementation of the veneers. After the teeth have been dried, a layer of unfilled resin should be placed on the etched enamel surface and the silaned porcelain. They are then thinned out with air, but not cured, as doing so might interfere with the seating of the veneers later on. The types of resin cement used in porcelain veneer cementation will be discussed in section 1.6.4.

The veneers are "tacked" on by light curing for five seconds, to allow removal of the excess resin (Parmeijer, 1991). Excess resin can also be removed prior to curing using either a small sponge or a fine brush dipped in unfilled resin (Tay et al., 1987). There should be little danger of dragging the underlying composite resin if the veneer fits properly.

g. Finishing

Any excess luting resin can be removed with a fine curette or sharp blade (Harley and Ibbetson, 1991) while the interproximal surfaces should be finished with fine abrasive strips. The contacts are then verified with waxed floss. The margins may be finished with the 30-fluted round-ended LVS #5, 6, and 7 tungsten carbide finishing burs[11], fine diamond burs or impregnated rubber points under water spray. Where more then one veneer is being cemented, the proximal surface of the first veneer should be finished first before placement of the neighbouring one. This is to prevent the excess resin from interfering with the seating of the next veneer to be placed. When all the veneers have been cemented and the excess luting resin has been removed with the margins roughly finished, the rubber dam should be removed and the occlusion checked. A final polishing of the veneer should be carried out 24 hours later to allow maximum bond strength to occur (Czarkowski, 1985).

Haywood et al. (1988) found that the best polished veneers observed with the scanning electron microscope and specular reflectance analysis were achieved with finishing grit diamonds (Micron Finishing System MF 1,2,3) followed by a 30-fluted carbide bur and

[11] Komet® Laminate Veneer Sysytem Set 4151.

diamond polishing paste ,Truluster[12] , which has a particle size ranging 2-5 micrometres on a webbed prophy cup. Some researchers have reported obtaining a polished porcelain surface similar to that of a glazed porcelain by using a bench lathe, with a pumice and tin oxide mixture (Sulik and Plekavich, 1981). Bessing and Wiktorsson (1983) confirmed the above results using a straight hand piece with the Shofu porcelain polishing system[13]. Whichever method of polishing is chosen, the criteria is to produce a smooth margin which is not plaque adherent and therefore promotes gingival health. Adjustments of any kind should be undertaken with fine diamonds under water coolant. The use of rotary instruments to finish the margins should be avoided as far as possible because such instruments tend to compromise the properly sealed marginal integrity and can cause microscopic crack lines. In addition, it is difficult to repolish the surfaces without the risk of ditching the cementum (Friedman, 1987). Polishing procedures remove the glaze which can never be restored. They also reduce the transverse tensile strength of the porcelain (which is not very high to begin with) by 50% or more. Crazing of the porcelain (Faunce, 1987) can also develop as a result of the sodium and potassium ion transfer. Unglazed porcelain has also been shown to cause rapid abrasion of the opposing dentition or restorations (Phillips, 1982).

Post operative instructions should be given to the patients. They should be advised to avoid the continuous use of acidulated fluoride solution and fluoride toothpastes, as both porcelain and composite silica are soluble in them (Yaffe and Zalkind, 1981). They should also delay food intake for 6-8 hours and desist from alcoholic beverages or medicated mouthrinses for 24 hours (Horn, 1983). To encourage the long term success of the cemented veneers, the patients must be given proper home care instructions and recalled frequently to ensure that a high standard of oral health care is maintained.

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[12] Brasseler USA ,Inc.
[13] Porcelain adjustment kit, Shofu Dental Corp.

1.3 Types of Dental Ceramic for Veneer Fabrication

The types of dental ceramics which can be used for the fabrication of veneers may be broadly categorized into :

1.3.1 Feldspathic porcelain
1.3.2 Castable glass ceramics
1.3.3 Machinable ceramics

1.3.1 Feldspathic porcelain

Dental porcelain is generally categorized by their fusing temperature into three classes (Phillips, 1982; Craig,1985; Combe, 1986). They are the high-fusing porcelain (1315°C-1370°C); the medium-fusing porcelain (1090°C-1260°C); and the low-fusing porcelain (870°C-1065°C). The high-fusing porcelains are used primarily for denture teeth and the medium-fusing porcelains for pontics (Lacy, 1977). The low fusing porcelains are used in metal ceramic restorations. The desirable properties of a metal ceramic veneering porcelain are, a high coefficient of thermal expansion which matches the metal alloy (Table 1.3.1) and a fusing temperature which is lower than the metal alloy (Lacy, 1977). The porcelain used for veneers in the refractory die technique should have a coefficient of thermal expansion similar to that of the refractory investment.

The composition of a typical feldspathic porcelain by weight is as follows (Craig, 1985):

Constituent	Percentage by weight
Feldspar	75-85
Quartz	12-22
Kaolin	3-5
Metallic pigments	<1

1. Feldspar

Feldspar is chemically known as potassium aluminum silicate ($K_2O.Al_2O_3.6SiO_2$). It is a naturally occuring mineral and precursor of common clay. It is crystalline and opaque in its mineral state, with an indefinite colour between gray and pink. Its function is to retain the form of the porcelain restoration during fusing. Feldspathic porcelain is manufactured by adding feldspar to glass modifiers or glass formers of the fluxing type, such as boric oxide. The feldspar-glass flux mixture can then be fritted at a specific temperature, according to the amount of feldspar required in the solution, until a completely homogeneous glass is formed. This would result in a lower firing temperature porcelain (McLean, 1979).

2. Quartz

Pure quartz crystals, silica (SiO_2), are used in dental porcelain to stabilize the mass during firing and provide a framework for the other ingredients (Craig, 1985).

3. Kaolin

Kaolin, as represented by the formula $Al_2O_3.2SiO_2.2H_20$, is a by product of weathering feldspar, where potassium silicate has been washed out by acidic water. Only the purest kaolin, prepared by repeated washing with water until all foreign materials have been removed, can be used in dental porcelain. Kaolin gives porcelain its property of opaqueness. It forms a sticky mass with water and contibutes to the workable consistency during moulding. However, it shrinks considerably when subjected to high heat and adheres to the framework of quartz particles.

4. Metallic pigments

The colouring pigments are metallic oxides ground with glass and feldspar. The mixture is then fused in a furnace and reground to a powder. The common metallic pigments present are titanium oxide for yellow-brown shades, manganese oxide for lavender, iron oxide for brown, cobalt oxide for blue, copper or chromium oxide for green, nickel oxide for brown and tin oxide to increase opacity (Craig, 1985).

A typical low-fusing dental porcelain has the following oxide composition by weight (McLean, 1979):

Oxides	Percentage by weight
SiO_2	69.36
B_2O_3	7.53
CaO	1.85
K_2O	8.33
Na_2O	4.81
Al_2O_3	8.11

The above material is non-aluminous, although aluminium oxide (Al_2O_3) is present. This is because the aluminium oxide present belongs to part of the glass network and there is no free alumina present. The aluminous porcelain developed in 1965 (McLean and Hughes, 1965) essentially has a composition similar to the above plus a 40-50% increase by mass of crystalline alumina. The addition of alumina has increased the compressive, tensile and flexural strength of the porcelain greatly. Its incorporation also hinders crack propagation within the material. It is therefore used as a core material in metal-free ceramic restoration.

The glass-forming matrix in dental porcelain is made up of silicon-oxygen network. Oxides of sodium, potassium, aluminium, calcium and boron can be added to the matrix to lower the fusing temperature and render the porcelain more viscous and resistant to devitrification (McLean, 1979).

Silicon and boric oxides function as glass-forming oxides on which dental glass can be formed. Calcium, potassium and sodium oxides act as fluxes which lower the softening temperature of the glass by reducing the amount of cross-linking in the silicon-oxygen network (McLean, 1979). The use of an intermediate oxide such as aluminium oxide helps to increase the hardness and viscosity of the glass. This is because dental porcelain requires a high resistance to pyroplastic flow and a low firing temperature

Some examples of feldspathic porcelains used in veneers are as follows (Wassenaar, 1990; Braze, 1986):

Product	Manufacturer
Mirage	Chameleon Dental Products Inc., KS, USA.
Optec porcelains	Jeneric Pentron Inc., Wallingford, CT, USA.
Vitadur®-N	Vita Zahnfabrik, Bad Säckingen, Germany.
Vitadur®-Alpha	Vita Zahnfabrik, Bad Säckingen, Germany.
Cerinate	Den-Mat® Corporation, Santa Maria, CA, USA.
Ceramco II	Ceramco Inc., East Windsor, NJ, USA.
G-Cera	G.C International, Scottsdale, Arizona, USA.
Shademate porcelain	Dentsply/York Div, York, PA, USA.
PVS porcelain	S.S. White Co., Holmdel, NJ, USA.

The newly developed Vitadur®-Alpha[14] porcelain contains opalescent frits which, according to the manufacturer, demonstrate reflection and absorption characteristics under widely differing light conditions. Vitadur®-Alpha has a refractive index and reflective characteristics similar to that of natural teeth. These properties make it an aesthetic material for veneers[15] . Whichever brand of porcelain is selected, it is essential that the coefficient of thermal expansion of the refractory die matches that of the porcelain if this system of manufacture is employed.

In addition to the properties summarized in table 1.3.1, the other properties of feldspathic porcelain also include (Craig, 1985):

Volumetric shrinkage	32-37%
Specific gravity	2.2-2.3
Transverse strength	62-90 MPa
Shear strength	110 MPa
Tensile strength	< 34 MPa

[14] Vita Zahnfabrik, Bad Säckingen, Germany.
[15] Vitadur Alpha Catalogue 1992.

Table 1.3.1

Physical property data of restorative materials and tooth structures (Grossman, 1983)

Reference	Cast Ceramic (1)	Enamel (2)	Dentine (2)	Porcelain (1)	Composite (2)	Gold Alloy (2)	Amalgam (2)
Density g/cm^3	2.7	3.0	2.2	2.4	2.0	14.0	11.0
Refractive Index	1.52	1.65	-	-	-	0	0
Translucency	0.56	0.48	-	0.27	.55-.70	0	0
Thermal Conductivity $cal/sec/cm^2/^\circ C/cm$	.0040	.0022	.0015	.0030	.0026	.7	.055
Thermal Diffusion mm^2/sec	.800	.469	.183	.640	.675	119	9.6
Coefficient of Thermal Expansion $x10^{-6}/^\circ C$	7.2	<11.4>	-	8.0	26-40	14.4	22-28
Modulus of Rupture MPa	152	10.3	51	75.9	45.5	448	69
Compressive Strength MPa	828	400	297	862*	194	-	379
Modulus of Elasticity GPa	70.3	84.1	18.3	82.8	16.3	90	62
Microhardness KNH_{100}	362	343	68	460	30	90-220	110

(1) Internal Measurements. Physical Properties Department. Corning Glass Works. Corning. NY.

(2) Restorative Dental Materials. R.G. Craig ed. C.V. Mosby Co. 1980.

*Dental Materials. Properties and Selection. W. J. O'Brien ed. Quintessence Publishing. 1989.

1.3.2 Castable glass ceramics

Two main types of castable ceramics can be used for the fabrication of veneers. They are the castable glass ceramic, Dicor®[16] (Grossman, 1985), and the castable apatite, CeraPearl[17], which produces hydroxylapatite microcrystals when the casting is heat treated (Hobo and Iwata, 1985b). Only the Dicor® material will be described, since it is one of the materials that will be used in the experiment.

In the 1930s, Frederick Carder of the Steuben Division of Corning Glass Works created three dimensional glass articles using the lost wax technique (Grossman, 1983). However, the crossover from glass into the stronger ceramics came with the invention of glass-ceramics[18] by S.D. Stookey of Corning Glass Works in 1957. The conversion of glass into ceramics incorporates a nucleating agent which acts as a starting point for the controlled growth of crystals within an amorphous matrix. This occurs during a regulated heat treatment or ceramming cycle (Grossman, 1988). The properties of glass ceramics are dependent on the type of crystals grown and the extent of the growth within the parent glass. This controlled growth of the crystals results in microstructures which are homogenous, nonporous, and uniform in size. Grain size varies from a few hundred angstroms to a few micrometres (Grossman, 1983). In 1968, glass ceramic technology was first applied in dentistry for fabrication of denture teeth (MacCulloch, 1968). Research work by Muller (1974) and Kasloff (1977) has also indicated the use of glass ceramics in dentistry.

From Grossman (1988), we learn that the main glass ceramic systems are:

1. Beta-spodumene glass ceramics

Commonly known as Corning Ware®, this material has a very low coefficient of thermal expansion ($1.2 \times 10^{-6}/°C$) and is considered to be thermally unbreakable under normal use. Its opacity is due to the nucleating agent, titanium dioxide.

2. Beta-quartz glass ceramics

Chemically similar to the beta-spodumene glass ceramics, beta-quartz glass ceramics contain beta-quartz solid solution crystals which are ultra-fine and have ultra-low thermal expansion.

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[16] Dentsply/York Div., York, Pa, USA.
[17] Kyocera International, Japan.
[18] Pyroceram, Corning Glass Works, Corning, N.Y. USA.

This material is useful for telescope mirror application, transparent cookware and for dark coloured counter top cooking surfaces.

3. Cordierite glass ceramics

These glass ceramics, produced by the crystallization of cordierte ($Mg_2Al_4Si_5O_{18}$), are used as electromagnetic windows or radomes for guided missiles. They combine strength, hardness, and temperature resistance with the necessary dielectric properties at radar frequencies.

4. Lithium disilicate glass ceramics

Also known as photosensitive glass ceramics, these glass-ceramics are obtained through the use of selective nucleation and subsequent growth of lithium silicate crystals ($Li_2Si_2O_5$).

5. Mica glass ceramics

This type of glass-ceramic is based on the crystallization of fluorine-containing mica crystals. Mica is a sheet-silicate mineral which grows to a penny-shaped crystal morphology. The interlocking microstructure results in materials capable of being machined. The present castable ceramic for dental applications is a special member of the family of machinable glass-ceramics (Grossman, 1972; Adair, 1984). The crystal phase is mica, but does not contain boron or alumina. These crystals have a similar refractive index to the surrounding residual glass thereby enhancing translucency.

This mechanically machinable material, containing tetrasilicic fluormica crystals ($K_2Mg_5Si_8O_{20}F_4$), was pursued by D.G. Grossman in 1972 for use in decorative applications. The material's flexibility and plate-like morphology add strength and resistance to fracture propagation. These qualities led to its application in dentistry in 1977 (Grossman, 1983). This material has superior aesthetic and physical properties. It can also be cast accurately using the lost wax technique (Grossman, 1983). The castable glass system known as Dicor® was marketed in 1984.

Composition of tetrasilicic-mica glass ceramics (Grossman, 1972)

	Percentage in weight			
Constituent	I	II	III	IV
K_2O	11.0	13.5	15.5	15.1
MgF_2	10.6	10.4	10.2	10.1
MgO	16.4	13.5	13.2	12.3
SiO_2	62.0	60.5	59.1	58.8
As_2O_5		2.0	2.0	1.9
ZrO_2				1.9

The castable ceramic material is supplied as small ingots of four gram in the vitreous or non-crystalline state. It is comprised of the oxides of silica, potassium and magnesium, and a magnesium fluoride. Small amounts of aluminium oxide and zirconium oxide are also incorporated for durability, and a fluorescing agent is added for aesthetic reasons.

Fluoride in the composition acts in several ways:

1. As a nucleating agent to facilitate transformation into a semi-crystalline state.
2. As a source of fluoride ions which are an essential component of the crystalline phase.
3. To help provide sufficient fluidity when the ingot melts to ensure that the investment mould fills completely.

Properties of the Dicor® glass ceramics

The glass ceramic retains its amorphous structure throughout the casting process. After the casting is obtained by the lost wax technique, the glass appears transparent and is said to be in the green state. The non crystalline glass is then converted into ceramic by a precise temperature controlled heat treatment, a process known as ceramming where nucleation and growth of mica-type crystals occur within the body of the casting. Electron micrographs of the glass ceramic during the ceramming process taken at different stages showed the emergence of tiny mica grain crystals of about 400 Å diameter at 650°C, with the material appearing transparent. At 960°C, the crystals begin to sharpen their form and the material loses its transparency. Further heating to 1075°C allows the crystals to develop better and this temperature is held for six hours to allow the mica crystals to grow and elongate until

they contact one another. Crystallization process is completed when all of the mica forming components available in the parent glass are used up (Grossman, 1983). These interlocking crystals within the matrix enhance the strength and fracture resistance of the material and help deflect and divert fractures on a microscopic level, enabling the material to be ground and polished with rotary instruments without physical degradation.

Modulus of rupture

Being a monolithic structure, the intrinsic strength of the glass ceramic is distributed throughout the body of the castable ceramic restoration such that any cracks, if present, will not propagate. The modulus of rupture or the internal body strength of the ceramic is 152 MPa[19] which is superior to that of natural enamel unsupported by dentine (10.3 MPa) and dental porcelain (75.9 MPa) (Table 1.3.1).

Compressive strength

The compressive strength of the castable glass ceramic is 828 MPa, which is superior to natural unsupported enamel (400 MPa), but slightly inferior to the compressive strength of dental porcelain (862 MPa) (Table 1.3.1).

Wear

The similarities in density and hardness of the glass ceramic and enamel helps in reducing the gross wear of the opposing enamel (Grossman, 1983). However, a comparative study on the wear of enamel when opposed by glazed Dicor® and dental porcelain (Ceramco) showed that 29% of the cast ceramic crowns and 83% of the metal-ceramic crowns produced facets which represented wear greater than observed in adjacent natural teeth (Ellison et al., 1989). Delong et al. (1989) also found that enamel opposing the unstained Dicor® suffered the least wear when compared to externally stained and unstained dental porcelain (Ceramco). Krejci et al. (1991) found that the wear resistance of Dicor® was within the range of enamel wear.

Fracture resistance

The fracture resistance of resin bonded Dicor® crowns was 66% higher in load resistance than the non bonded crowns (Grossman and Nelson, 1987). However, there was no significant difference in the fracture resistance of full Dicor® crown with external staining

[19] Internal measurements, Physical Properties Department, Corning Glass Works, Corning, N.Y. USA.

and Dicor® used as a substructure supporting Vitadur N porcelain (Bales et al., 1990). Further studies showed that the highest overall fracture resistance was obtained with 0.5 millimetre resin bonded ceramic to etched enamel (Duffin et al., 1989). However, evaluation of different porcelain crown systems reveals that the Dicor® crown has a lower fracture resistance than metal-ceramic crowns (Rodrigues et al., 1987).

Thermal properties

The coefficient of thermal expansion of the castable glass ceramic is low (Table 1.3.1). It has a coefficient of thermal expansion similar to enamel compared to the polymers and metals. Thermally, the low conductivity of the ceramic makes it a poor conductor of heat and cold to the underlying tooth structure. Aluminous porcelain (Vitadur N[20]) can be used to veneer Dicor® crowns due to their similar coefficient of thermal expansion (McLean, 1988; Geller and Kwiatkowski, 1987). This is however no longer a usual practice as there have been reports of delamination after 4-5 years.

Radiographic Properties

The similarities between the radiographic density of the ceramic and enamel allow for the radiographic detection of dental caries, and the examination of posts, pins, and fit of the restoration (Grossman, 1983).

Chemical Durability

The ceramics tolerate tests involving a wide pH range and elevated temperature to accelerate any potential corrosive mechanisms (Adair and Grossman, 1984; Grossman, 1985).

Biocompatibility

Sensitive cytotoxicity and rabbit muscle implant tests showed Dicor® to be biocompatible. Further tests, such as acute oral hamster cheek pouch, dermal sensitization, haemolysis, and mutagenic potential (Ames' test) also showed negative findings of any incompatibility (Adair and Grossman, 1984; Grossman, 1985).

[20]Vita Zahnfabrik, Bad Sachingen, Germany.

Fit

The lost wax technique enables the wax pattern to be cast accurately and this ensures a proper fit. Dicor® restorations have been reported with marginal accuracies ranging from 28 micrometres[21], 46.6 micrometres (Davis, 1988), 48 ± 7 micrometres (Holmes et al., 1992), 57 micrometres (Weaver et al., 1991) to 65.3 micrometres (Abbate et al., 1989). However, the fit of cast gold crowns is reported to be superior to Dicor® crowns (Trindade et al., 1989; Al-Saif et al., 1990).

Bond Strength

Etching and silane treatment of Dicor® veneers has resulted in a high bond strength with resin cement (McInnes-Ledoux et al., 1987; Eden and Kaciez, 1987; Bailey and Bennett, 1988). Etching times did not have a significant effect on the bond strength of Dicor® machinable glass ceramic (MGC) to resin. A low viscosity dual cure resin cement, together with etching and silane treatment of the glass, all contributed significantly to an increase in bond strength (Nathanson, 1991). However, the bond strength between the silanated Dicor® samples to the composite resin was found to be inferior to that of silanated dental porcelain, although both showed enhanced bond strength after silane treatment (Tjan and Nemetz, 1988).

Aesthetic Qualities

The translucency of the Dicor® glass material is similar to enamel. This close match is due to the numerous mica crystals that constitute the structure of the ceramic. These crystals have a similar index of refraction to the surrounding glass phase which bonds the material. The high translucency of the material also provides a "chameleon" effect as the crown acquires tones from the adjacent teeth and restorations (Grossman, 1985). The shade of the restoration is obtained from a combination of an external colouring system and the use of coloured luting cements. The external colouring system has a few advantages. It allows independent control over the hue, chroma and value. The hue can be controlled through the selection of the porcelain shade, the chroma, by the number of applications, and the value, by combining the selection of enamel colour and the extent to which it is raised onto the facial surface. Microprobe analysis, taken across the interface of the external porcelain colourant and Dicor®, shows there is an exchange of potassium and sodium ions between the two. This exchange of ions has resulted in a physical and chemical bonding with the

[21] Dicor® Research Report. Fit of Dicor castable ceramic crowns. Dicor research report. 1986;2(1).

crystalline matrix. The colour will not be lost after cementation in the mouth. However, acidulated fluoride rinses can degrade any ceramics and may therefore, remove the colourants (Malament, 1987). The disadvantage of the external colouring system is that it does not provide a true depth to the colour and this can result in a restoration that looks painted (Campbell, 1990). Because of this problem, the "Willi's Glass crown" and the "Dicor-Plus" systems were developed. Both systems involve veneering a Dicor® coping with a layered porcelain build up which is matched to the coefficient of thermal expansion of Dicor® (Campbell, 1990; Geller and Kwiatkowski, 1987).

The coloured luting cements also determine the final shade of the restorations. These coloured luting cements are matched with the coloured die spacers used in the laboratory to coordinate the background used by the technician and the dentist in the final restoration.

Implication of Dicor® crowns and the periodontium

Plaque is the key etiologic agent to both caries (McDonald, 1985) and periodontal problems (Vogel and Alvares, 1985). In-vivo studies of plaque identification and adherence at the tooth-cast glass ceramic crown interface showed that plaque does not adhere significantly to the ceramic surface with or without colourants (Grossman, 1985; Jensen et al., 1989). Bacterial growth found on the surface of these restorations is seven times less than that found on natural tooth surfaces (Savitt et al., 1987).

1.3.3 Machinable ceramics

The use of machinable ceramics follows the introduction of CAD/CAM (computer aided design/computer assisted manufacturing) technology in dentistry. The CAD/CAM technologies were merged and appeared commercially in the 1970s. At the same time, a number of dental groups began investigating the possibility of developing a CAD/CAM system for prosthodontic application. The CAD/CAM technology involves taking a three dimensional optical impression of the tooth preparation using an oral video camera. This replaces conventional impression techniques. The manufacturing steps of the restoration, which are normally carried out in the dental laboratory, are substituted by the computer aided design of the restoration directly onto the monitor and the computer assisted machining of the restorations.

Two main types of ceramic materials can be used with this kind of technology. They are the conventional feldspathic porcelain containing quartz e.g Vita Mark I and II Porcelain blocks[22] or Ceramco[23] and the machinable castable glass ceramic, Dicor®/MGC[24], which contains no quartz particles (Leinfelder et al., 1989).

Properties of the Vita Cerec® Porcelain blocks

The two main types of Vita Cerec® Porcelain blocks are the older Vita Mark I®, also known as Cerec Vita Bloc®, and the newer Vita Mark II®. The Vita Mark I® porcelain blocks are no longer in production and have now been superceded by the Cerec® Vita Bloc® Mark II.

Shear Strength

The acid etch pattern and bond strength of three types of machinable ceramic materials (Dicor®/MGC, Cerec Vita Bloc®, and Cerec® Vita Bloc® Mark II) to composite resin was studied. The highest shear strength was observed in the bonding between the composite resin and Vita Mark II, followed by Cerec Vita Bloc® then Dicor®/MGC glass ceramic. Bonding to Dicor® /MGC glass ceramic produced the lowest shear strength, which was not improved by the choice of etching agent or composite resin (Hofmann and Haller, 1991).

Wear

The wear of Vita Mark I and Vita Mark II porcelain was found to be less than that of human enamel, while that of Dicor®/MGC was higher in a wear experiment carried out in a six-chambered chewing machine. The abrasion potential against opposing enamel cusps was high with Dicor®/MGC and Vita Mark I, but moderate with the new finer Vita Mark II (Krejci, 1991). However, another study involving an "artificial mouth" programmed to reproduce masticatory cycles, showed that Dicor®/MGC caused the least amount of wear in opposing enamel (Grossman, 1991).

Flexural strength

The flexural strength of ceramics is partially dependent on its surface roughness. A study to determine the influence of four types of diamond coated grinding discs on the flexural strength of Vita Mark I, Vita Mark II porcelain and Dicor®/MGC glass ceramic showed that

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[22] Vita Zahnfabrik, Bad Sachingen, Germany.
[23] Johnson & Johnson, East Windsor NJ, USA.
[24] Dentsply International, York, Pa.,USA.

the design and the grain size (126 and 91 micrometres) of four types of diamond coated grinding discs did not cause any significant differences (Lüthy et al., 1991a). The flexural strength of feldspathic Vita Mark I and Vita Mark II porcelain was 73-87 MPa. This was significantly lower than that of Dicor®/MGC glass ceramic, which was 145-170 MPa (Lüthy et al., 1991a). No significant difference was found between the flexural strength of Vita Mark II porcelain or Dicor®/MGC glass ceramic when the surfaces were etched or silane treated, or when the bonding agent was applied (Lüthy et al., 1991b).

The effects of machining and grinding on the machinable ceramics

A fractographic analysis of machining effects on Vita Mark I, Vita Mark II porcelain blocks and Dicor®/MGC glass ceramic to evaluate some aspects of machinability showed that these ceramic materials follow a classic log-log relationship between fracture stress and fracture-feature radius. In all cases, the test bars appeared to have fractured from machining-induced flaws (Kelly et al., 1991). Fractography is applied to determine the type of failure-originating flaw, its location, and the stress at failure. This is achieved by studying the characteristic features related to crack propagation. In another study, Hahn and Löst (1991) examined the ceramic structures of the early Vita Mark I porcelain in the immediate spatial relationship of surfaces ground by the Cerec® system. They found a net of cracks, resembling delamination below the ground surface, regardless of the geometric shape or size of the inlays.

1.4 Techniques for Ceramic Veneer Fabrication

Various techniques for producing ceramic veneers have been documented. Some have evolved from existing porcelain techniques, while others have utilized new materials and techniques.

The first technique for the fabrication of ceramic veneers evolved from that of Pincus who used a platinum matrix to support the veneer. The method has also been used by Horn (1983), Calamia (1985), Quinn et al. (1986), Plant and Thomas (1987), Nasedkin (1988) and Garber et al. (1988).

The second technique is the refractory phosphate bonded investment technique without the use of any matrix (Garber et al., 1988; Clyde and Gilmour, 1988).

The third technique is an extension of the old castable ceramic theories first put forth in the 1920s. Two distinct systems of castable ceramics now exist and they are known commercially as the castable ceramic Dicor® system[25] and the castable apatite Cerapearl system.[26] Another technique, which can also be used for the fabrication of veneer, is the IPS Empress system which involves the high temperature pressing of leucite-reinforced glass ceramics, developed by Ivoclar-Vivadent.

The fourth technique involves the one visit CEREC® CAD/CAM method of fabrication, invented by Mormann et al. (1989).

Only the refractory die technique, castable glass Dicor® and the CAD/CAM Cerec® techniques will be described, as they are the methods for veneer fabrication being investigated in this study.

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[25] Dentsply/York Div., York, Pa
[26] Kyocera International, Japan

1.4.1 The refractory die technique for veneer fabrication

Introduction

As the platinum foil technique of fabricating crowns was found to produce a flawed internal surface and faulty marginal adaptation (Southan and Jorgensen, 1972), the refractory die technique was developed. This technique involved building the porcelain directly onto high temperature investment material without the platinum foil matrix. It was thought that this technique would provide a better fitting veneer when compared to the platinum foil technique (McLaughlin, 1986; Harbert and Dudek, 1988).

The refractory investment should have a coefficient of thermal expansion similar to the porcelain used for veneering. If the difference of coefficient of thermal expansion between the two is too great, there is a risk of disproportionate expansion which may result in fractures in the porcelain and an improper fit. The refractory investment should also be dimensionally stable at moderate firing temperatures and ideally, provide a neutral background for checking the shade of the restoration.

The technique

As with all other procedures, an accurate impression of the tooth preparation and subsequent care in quality assurance during the laboratory fabrication of the veneer are most important if a good fit of the restoration is to be achieved.

A hard and abrasive resistant dental stone or epoxy cast should be chosen for pouring the master model. After the die localization of each preparation, the dies are separated from each other by sawing them apart carefully. A lubricant is applied to the separated and localized dies and an elastomeric impression of these master dies taken. A die spacer is usually not required unless extra space is required for masking badly discoloured teeth. Adequate space is usually developed during the fabrication process, for example, when the sealant is applied to the model or when the fitting surfaces are sandblasted and etched. Too thick a layer of composite resin for luting will weaken the entire restoration (Greggs, 1988).

Refractory die materials, such as Gresco Cerevest II[27], Vita Hi-Ceram[28] or Vitadur-vest[29], can be used provided the coefficient of thermal expansion of the porcelain to be used is

[27] Gresco Product Inc., Stafford, Texas
[28] Vita Zahnfabrik, Bad Säckingen, Germany.

compatible with that of the refractory die and provided that the manufacturer's instructions are strictly adhered to.

The individual refractory dies are removed from the duplicate impression after they have set completely and then degassed to avoid contamination of the ceramic with the ammoniated gases inherent in the refractory material. The manufacturer's instructions for the degassing process are to be followed for the particular refractory material chosen.

The margins of the preparation are then marked with a refractory marking pen. To ascertain the thickness of the veneer, Terry (1990) suggested marking the most prominent buccal surface of the preparation with the refractory pencil, and creating an indentation with a small round bur on the lingual surfaces of the preparation opposite the dot on the buccal surface. The thickness of the tooth between these two points is measured with a caliper and recorded before fabrication of the veneers. The average veneer thickness is 0.5-0.7 millimetre (Millar, 1987; Faunce, 1987). Hui et al. (1991) found that, contrary to common belief, the strength or load carrying capacity of the veneer is not proportional to its thickness. The strength is derived from bonding the veneer with the composite luting resin. This complex is then strongly bonded to and supported by the underlying enamel.

After the margins and the thickness of the preparation have been marked and recorded, the degassed refractory dies are either soaked in distilled water or conditioned with the modelling liquid for a few minutes (Harbert and Dudek, 1988). This procedure helps to prevent the die from drawing moisture from the porcelain. Alternatively, a thin mix of glaze can also be applied to seal the die beyond the margins. This prevents the die from absorbing moisture from the porcelain mixture and air voids forming under the porcelain (Greggs, 1988). The sealed die is then fired according to the manufacturer's instructions. Harbert and Dudek (1988) recommend a two stage build up technique to control shrinkage and promote a better porcelain adaptation to the refractory die. The first layer of thin porcelain applied is sintered, followed by a second layer which forms the contour of the restoration. This second layer of porcelain is overbuilt to compensate for firing shrinkage (Lang and Starr, 1992). It is important that the porcelain and the refractory die should be dried in front of an open muffle before firing. This helps to evaporate the excess moisture in the porcelain build up which otherwise may cause cracking and fracturing in the veneer, if present. A third firing is usually required to bake the porcelain added in areas of marginal deficiency. Each bake is fired at a temperature approximately 10°C lower than the one before. The veneers are then carefully contoured with diamond burs or porcelain stones and the occlusion checked.

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[29] Vita Zahnfabrik, Bad Säckingen, Germany.

After the veneers are stained, glazed and bench cooled, the bulk of refractory material can be removed from the veneers with a bur. The remaining investment material can be removed from the fitting surface by sandblasting with 20-50 micrometre particles of aluminum oxide at 1-2 pressure bar. Care must be taken not to damage the margins. The veneers are then cleaned in an ultrasonic detergent bath and a rubber wheel is used to lightly remove all the overextensions from the edges before the fit is checked on the master die. The fitting surfaces of the veneers can either be etched and silane treated in the laboratory or at the chairside before cementation by the dentist.

Advantages of the refractory die technique:

1. The white background of most refractory die allows a more accurate application of porcelain shades compared with the metallic greyish background of the platinum foil matrix.

2. The technique is simple and inexpensive, as it does not require extraordinary equipment.

3. The ceramist is able to incorporate internal staining and characteristic features during the porcelain build up, giving a more life like appearance when compared to the castable glass technique or the CAD/CAM technique.

Some limitations of the refractory die technique:

1. Staining or glazing of the veneer is not possible once it has been removed from the refractory die. Therefore, the dentist will not be able to make any major aesthetic alterations and the veneers will have to be remade should the need arise.

2. The margins of the veneers may be abraded during the sandblasting process to remove the refractory materials (Sorensen, 1992). This may explain why a better fit has been obtained with the platinum foil technique compared with the refractory die technique (Sorensen, 1992; Sim and Ibbetson, 1993).

1.4.2 The castable glass technique for fabrication of veneers

Introduction

Currently, three methods are available for the fabrication of veneers using the lost wax technique. They are the IPS Empress® system, the Cerapearl® system and the Dicor® techniques. The lengthy ceramming processes in the Dicor® and the Cerapearl® systems are not required with the IPS Empress® system, as the controlled crystallization phase in the leucite reinforced glass ceramic is produced by the manufacturer.

As the Dicor® and the Cerapearl® systems are similar, only the Dicor® technique of veneer fabrication will be described.

Glass ceramics were first applied in dentistry when a set of denture teeth of various opacities were fabricated (MacCulloch, 1968). Initially, the glass ceramics were found to be too weak to withstand the oral environment. The use of air pressure and a vacuum, combined with a lost wax casting machine technique, was found to produce a stronger material with properties similar to those of human enamel (Grossman, 1985).

The technique

An accurate impression is taken of the prepared teeth. Master and working models are then poured in hard dental stone. The dies are prepared in the same way that crown and bridge dies are prepared. A layer of die spacer is applied evenly without touching the margins. Due to the high translucency of Dicor® material, an important factor contributing to the final shade is the colour of the cement used by the dentist. Dicor® die spacers are provided in the same shades as Dicor® cements. The dentist should inform the laboratory of the shade chosen so that the laboratory can select the appropriate shade of die spacer and then inform the dentist. The dentist can then choose a luting cement which corresponds to the shade of the die spacer. The Dicor® Die Spacer Shade Selection Chart recommends the die spacer to be used with the tooth shade selected for the restoration.

The anatomical contours are carved in wax in their entirety and the margins checked under magnification for any excess, which is then removed and finished. The wax patterns are sprued and invested in a phosphate bonded investment material according to the manufacturer's instructions as soon as possible. A maximum of four veneers can be

invested in one casting ring. After the investment has bench set for an hour, it is heat soaked for 30 minutes at 250°C and then burned out at 900°C[30].

The castable ceramic material is supplied as a four gram ingot in a disposable crucible. The ingot is placed in the electric muffle of a specially designed casting machine, heated to a casting temperature of 1360°C and held for six minutes, after which the melted glass is forced into the mould. The casting is completed by a motor driven centrifugal casting machine. The centrifuge will spin for about 4 minutes to maintain continuous pressure on the casting during the slow cooling process. The casting is then bench cooled and divested. After divesting carefully, the button and part of the sprue is removed and the casting invested in a gypsum bonded investment material and heat treated (cerammed) for six hours at 1075°C. The ceramming process produces a crystalline state in the ceramic which gives it the superior physical properties. The casting which appears opaque-translucent after ceramming, is then fitted onto the die. The outer surface is finished with conventional finishing stones, grit blasted and cleaned ultrasonically in water. The desired shading porcelains or veneering porcelains are then applied on the surface for shading and characterization and fired according to the manufacturer's recommendations. The fitting surface of the veneer is then etched with a 10% ammonium bifluoride gel for 30 seconds according to the manufacturer's instructions (Hofmann and Haller, 1991). The silane coupling agent can then be heat cured onto the fitting surface or applied at the chairside by the dentist. However, the bond strength for the chemically-cured silane is only 70% as effective as the heat cured surface after decontamination with alcohol or acetone. Therefore, it is recommended that the Dicor laboratory routinely apply and heat cure Dicor® Coupling Agent [31].

Advantages of the castable glass technique:

1. The casting is more accurate than the traditional gold castings or metal alloys because of the gradual transition of liquid to solid and the greater wettibility of glass oxides to the investment (Adair and Grossman, 1984).

2. The casting can also be fired repeatedly, if necessary, without affecting the marginal integrity, hardness or translucency, as the material is dimensionally very stable (Adair and Grossman, 1984).

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[30] Dicor® Laboratory Technique Manual.
[31] Dicor® Clinical Instruction Manual.

3. Waxing the pattern for the veneer is a significant advantage over the porcelain technique, which requires overbuilding to allow for shrinkage during firing. This procedure therefore improves the marginal fit and aesthetics, and eliminates chairside contour adjustments (Lang and Starr, 1992).

4. The Dicor® material, which has physical properties desirable of a restorative material, has been discussed in section 1.3.2.

5. The casting can be used as a coping for a porcelain of similar coefficient to be veneered on, such as Dicor® Plus or Vitadur N[32] porcelain in the"Willi's Glass crown". This provides a more life-like shade and characteristic modifications.

Limitations of the technique:

1. Shading porcelain alters the abrasive nature of Dicor® surfaces. Studies have shown that enamel opposing the externally stained ceramic wore at a rate 10-15 times greater than the enamel opposing discs of Olympia metal which acted as a control.(Delong et al., 1989).

2. The underlying white cerammed glass might be exposed, should the need for cosmetic contouring or adjustment of the veneer be required (Garber et al., 1988; McLaughlin, 1988).

3. The 0.5-0.75 millimetre enamel reduction required to maintain strength of the cast glass ceramic will inevitably encroach on the dentine, especially at the cervical area. The bond between dentine and composite is not as predictable as that of etched enamel and composite.

4. Due to the translucency of the material, badly discoloured teeth cannot be masked as effectively.

5. The longevity of the externally shaded porcelain is questionable.

6. This technique is not favourable for closing large diastemas because it is difficult to mask the unsupported ceramic where the diastemas are. The unsupported ceramic will appear grey, due to the dark reflection from the back of the mouth.

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[32] Vita Zahnfabrik, Bad Säckingen, Germany.

7. The initial set up cost of the complete Dicor® system is high.

1.4.3 The CAD/CAM technique for veneer fabrication

Introduction

The advent of interactive computer graphics, computer-aided design and computer-aided manufacturing have revolutionalized dentistry. It is now possible to provide the equivalent of a cast restoration within one appointment. Dental CAD/CAM systems are being developed to bring automation to the fabrication of dental restorations. The Cerec® system[33] is one of the best known and is now widely available. Other systems, such as the Duret system[34], produced by Sopha, the Dux system, also known as the Titan system[35], the Celay system[36], the Procera system[37] and the DentiCAD system[38] (Rekow, 1991) are also being developed.

The restoration of a tooth basically involves three components:

a. Data acquisition.
b. Restoration design.
c. Restoration fabrication.

With the CAD-CAM systems, data acquisition, that is impression taking and fabrication of models and dies, can be automated. Design, which is the current waxing process, is replaced with computer commands supplied either interactively by the user or by special programs called an expert system. Investing and casting techniques can be replaced by faster fabrication techniques used in modern manufacturing.

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[33] Siemens Dental Corp., Benshein, Germany.
[34] Lyon, France.
[35] DCS Dental, Allschwill, Switzerland.
[36] Mikrona Technologie, Spreitenbach, Switzerland.
[37] Nobelpharma Inc., Goteborg, Sweden.
[38] BEGO, Bremen, Germany and DentiCAD USA, Waltham, Mass.

The technique (Leinfelder et al., 1989; CEREC® Operator's Manual, 1984)

Since Cerec® is one of the best known and widely available systems, it will be described. The Cerec® system, an acronym for **ce**ramic **rec**onstruction, originally described by Mormann and Brandestini, was introduced to the dental profession for chairside customization of ceramic inlays, onlays and veneers in 1986 (Duret et al., 1988; Mormann and Brandestini., 1989). It consists of a three-dimensional video camera scanhead, an electronic image processor, a memory unit , and a processor (computer), which is connected to a miniature three-axis milling machine.

The optical impression

The teeth have to be prepared with either the gingivo-incisal or mesio-distal dimension conforming to the diameter of the milling disc to accommodate the limitations of the milling apparatus (Essig et al., 1991). Some light reflecting and contrasting medium powder (titanium oxide) is then applied evenly over the preparation before taking an optical impression. The optical impression is obtained by placing a small handheld intra-oral video camera with a 1 centimetre wide lens over the preparation. The camera, when positioned over the prepared tooth, emits an infrared light through the lens which is then reflected back to the scanning head and onto a photoreceptor. The intensity of the reflected light is recorded as voltage, which is, in turn, converted to digital form and transmitted to the computer.

Restoration design

A cursor, controlled by a track ball, is used to define the limits of the fixed veneer preparation image. The computer then draws a continuous line through all the points along the preparation margin. The completed tooth boundary line is stored in the disk and the restoration is ready to be milled.

Milling

Two main types of ceramic blocks can be used for the milling operation. The first type is a conventional feldspathic porcelain containing quartz, such as Vita[39] and Ceramco[40]. The

[39] Vita Zahnfabrik, Bad Säckingen, Germany.
[40] Johnson & Johnson, East Windsor NJ, USA.

second type is a machinable glass ceramics MGC/Dicor®[41], which does not contain any quartz particles.

A Vita Cerec® Mark II V5 veneer block of the selected shade is inserted in the chuck and the milling procedure is initiated. The restoration is generated by means of a diamond covered disk driven directly by a hydraulic drive in conjunction with a high velocity water spray. Recently, this traditional hydraulic unit has been superseded by a new electric version which uses an electric motor to drive the milling wheel. The electric driven milling generally produces a better fitting restoration than the hydraulic driven model (Liu et al., 1993). As the porcelain block rotates on its axis, the diamond wheel also rotates and translates up and down over the porcelain being cut. In the last stage of the milling operation, the milling disk separates the restoration from the rest of the ceramic block and the restoration falls to the bottom of the chamber where it is retrieved in preparation for cementation.

The shade and fit of the veneer is checked and adjusted accordingly on the tooth. Subsequently, the fitting surface of the veneer is etched with a hydrofluoric acid gel and then a silane coupling agent applied. The veneer is then cemented with a dual cure composite luting cement and finished in the usual way.

<u>Advantages of the CAD/CAM technique for veneer fabrication:</u>

1. An aesthetic ceramic restoration can be achieved within a single visit.

2. The porcelain veneer, when cemented, enjoys the physical and chemical properties similar to that of enamel.

3. No laboratory support is required.

4. A dental auxillary can be trained to operate and fabricate the restoration so that the dentist can utilize his time more efficiently.

---

[41] L.D. Caulk.

Limitations of the CAD/CAM technique for veneer fabrication:

1. The veneers cannot be characterized, stained or glazed at this point in time. Any aesthetic modification of the veneer required is dependent on the composite luting cement, where the long term colour stability is questionable.

2. This technique is unsuitable for a number of aesthetic restorative cases, such as, diastema closure, restoration of fractured incisor and masking of marked discolouration. These cases can be treated more easily by other more conventional methods for veneer fabrication.

3. Only one size of porcelain veneer block is available and the shades are limited to five (Vita shades A1, A2, A3, A3.5, and B3). Therefore, this technique is limited when restorations requiring shades and sizes other than the ones provided are indicated.

4. The restoration fabricated by this technique does not have as close a fit as that of a cast restoration. The interfacial marginal gap for veneers has been reported to be 248±26.7 micrometres pre-adjustment and 128±12.5 micrometres post-adjustment (Essig et al., 1991) and a median marginal gap of 95-230 micrometres (Cerutti et al., 1991).

5. The cost of the system is high.

1.5 Marginal Adaptation

1.5.1 Definition of marginal adaptation

"Adaptation" has been described as "the correct packing of filling material into a cavity" (Fairpo and Fairpo, 1987) or "the close approximation of a restorative material to cavity walls" (Boucher, 1974). The term "fit" has been defined as " the adaptation of any dental restoration" (Boucher, 1974). It can therefore be assumed that the two terms, fit and adaptation are synonymous.

Margin refers to the edge of a surface, which in a restoration, is equivalent to the counterpart of cavosurface margin of the cavity prepared for that restoration (Boucher, 1974).

The reference points for measurement and the descriptive terminology defining fit or adaptation vary considerably among investigators. The same term has been used to refer to different measurement, or different terms have been used to refer to the same measurement. This results in a constant source of confusion in reporting and comparing studies. For this reason, marginal adaptation in this review is interpreted as the apposition of the restorative material to the tooth at the margin.

1.5.2 The importance of good marginal adaptation

A good marginal adaptation is important in the prevention of caries and the protection of the cementing medium. It also determines the longevity of all types of restorations (L'Estrange et al., 1991). The space which exists between the restoration and the tooth preparation allows the accumulation of bacterial plaque (Löe, 1968; Abbate, 1989). Waerhaug (1960) and Löe (1968) have also reported that the plaque accumulated in this space is responsible for periodontal inflammation. Bjorn et al. (1970) also observed a direct association between the size of marginal defects and the degree of periodontal bone resorption.

Poorly finished margins in porcelain are believed to encourage plaque retention (Chan et al., 1989). Risks for secondary caries have been found to increase with both poor marginal quality and poor oral hygiene (Roulet, 1989). By improving the marginal adaptation of a restoration, cement exposure to the oral environment will be minimized, which in turn will reduce the rate of cement dissolution. When the cement is washed out or removed

iatrogenically during finishing procedures, a recess can be created where micro-organisms can accumulate (Sorensen, 1990).

1.5.3 The criteria for good marginal adaptation

According to Holmes et al. (1989), the criteria for a good marginal adaptation are the absence of:

a. Internal gap.
b. Marginal gap.
c. Vertical marginal discrepancy.
d. Horizontal marginal discrepancy.
e. Overextended margin.
f. Underextended margin.
g. Absolute marginal discrepancy.
h. Seating discrepancy.

a. Internal gap

This is the perpendicular measurement from the internal surface of the restoration to the axial wall of the preparation (Figure 1.5.1). In a veneer, this would refer to the distance between the labial surface of the preparation and the fitting surface of the veneer.

b. Marginal gap

This is the same perpendicular measurement from the internal surface of the restoration to the axial wall of the preparation at the margin (Figure 1.5.1). In a veneer, this would refer to the distance between the labial surface of the preparation and the fitting surface of the veneer at the margin.

c. Overextended Margin

This is the perpendicular distance from the marginal gap to the restoration margin (Figure 1.5.1b).

d. Underextended margin

This is the perpendicular distance from the marginal gap to the cavosurface angle of the tooth (Figure 1.5.1a).

e. Vertical marginal discrepancy

This is the vertical marginal misfit measured parallel to the path of withdrawal of the restoration (Figure 1.5.1).

f. Horizontal marginal discrepancy

This is the horizontal marginal misfit measured perpendicular to the path of withdrawal (Figure 1.5.1).

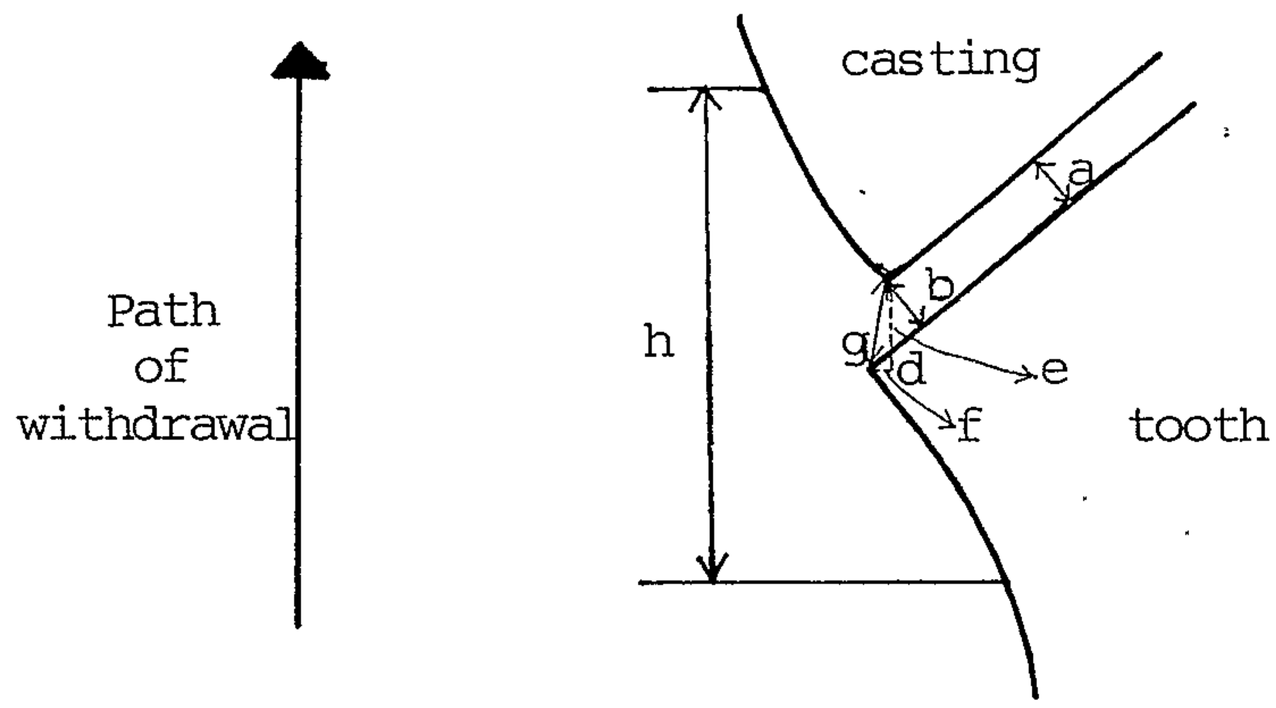
g. Absolute marginal discrepancy

This is the distance from the cavosurface angle of the preparation to the margin of the restoration and it represents the maximum measurement of misfit at the margin. It can also be defined as the hypotenuse of a right angled triangle, with sides designated as over or under-extended and the marginal gap, or as the angular combination of marginal gap and extension error (either over or under-extension) (Figure 1.5.1).

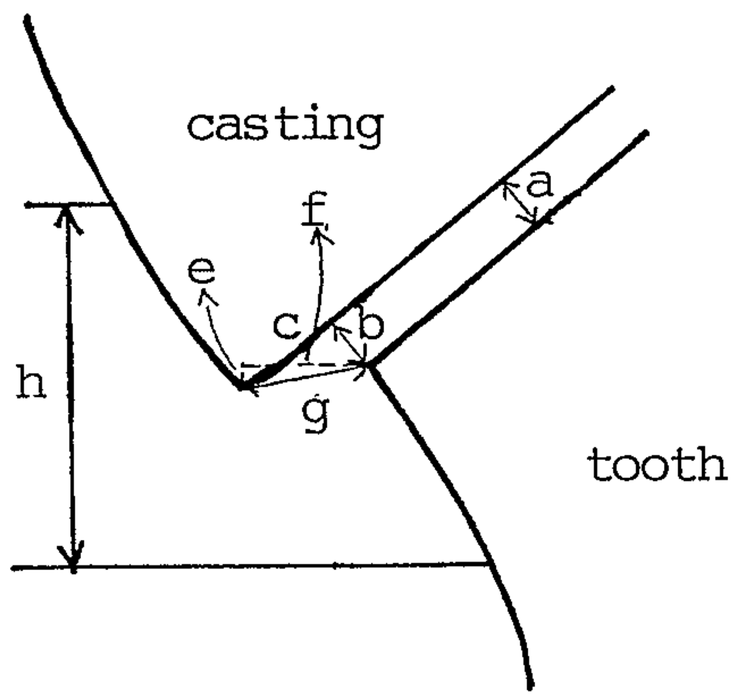
h. Seating discrepancy

This refers to the lack of seating of a restoration. The seating discrepancy is measured parallel to the path of withdrawal, from an arbitrary point on the external surface of the restoration to another arbitrary point on the tooth, away from the margin (Figure 1.5.1).

Figure 1.5.1 The types of misfit in a casting (adapted from Holmes et al., 1989)



(a) Underextended casting



(b) Overextended casting

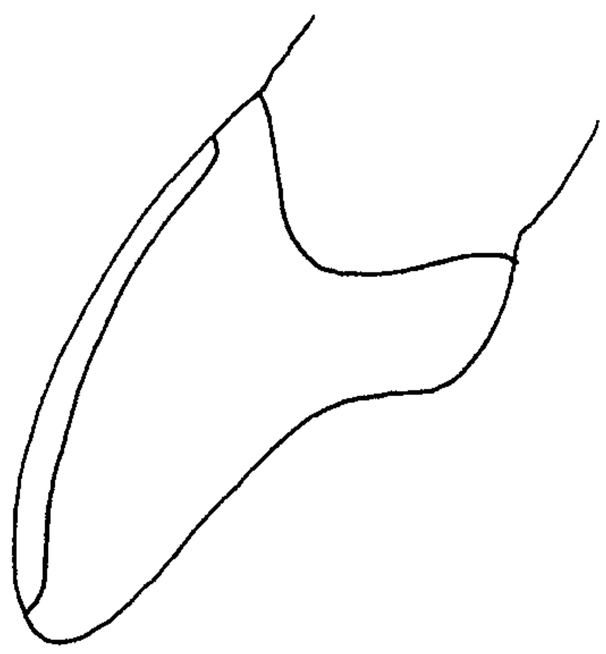
a Internal Gap
b Marginal Gap
c Overextended Margin
d Underextended Margin
e Vertical Marginal Discrepancy
f Horizontal Marginal Discrepancy
g Absolute Marginal Discrepancy
h Seating Discrepancy

The coincidence of the restoration margin and the cavosurface angle of the tooth constitutes a perfect fit (Figure 1.5.2a). Although a restoration without marginal gaps may not have the problems of cement solubility, presence of over-extension would have serious implications on the periodontal health (Holmes et al., 1989).

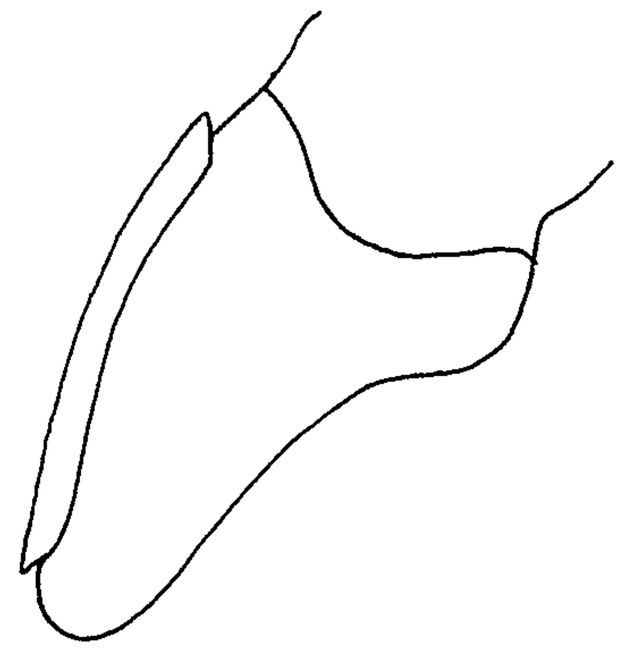
The types of marginal discrepancy that exist in a porcelain laminate veneer can be categorized into the following (Modified from Holmes et al., 1989) (Figure 1.5.2):

a. No marginal gap, no over or under-extension.
b. No marginal gap, but with over-extension (overcontour).
c. No marginal gap, but with under-extension (undercontour).
d. Marginal gap with no over or under-extensions
e. Marginal gap with over-extension.
f. Marginal gap with under-extension.

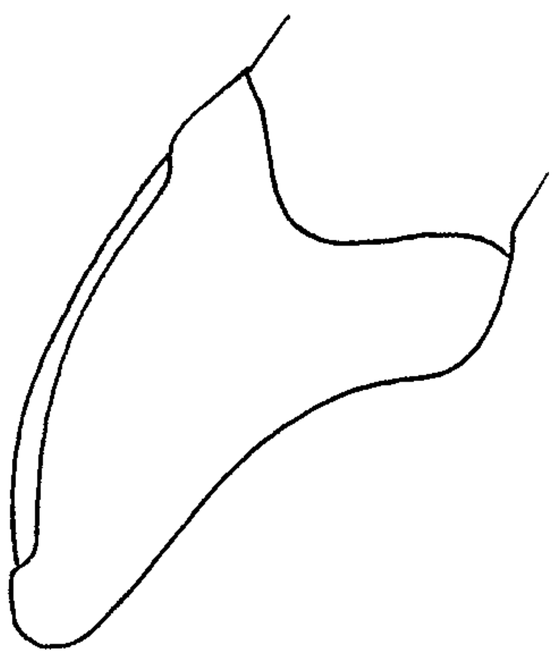
Figure 1.5.2 Types of marginal discrepancies in porcelain veneers (modified from Holmes et al., 1989)



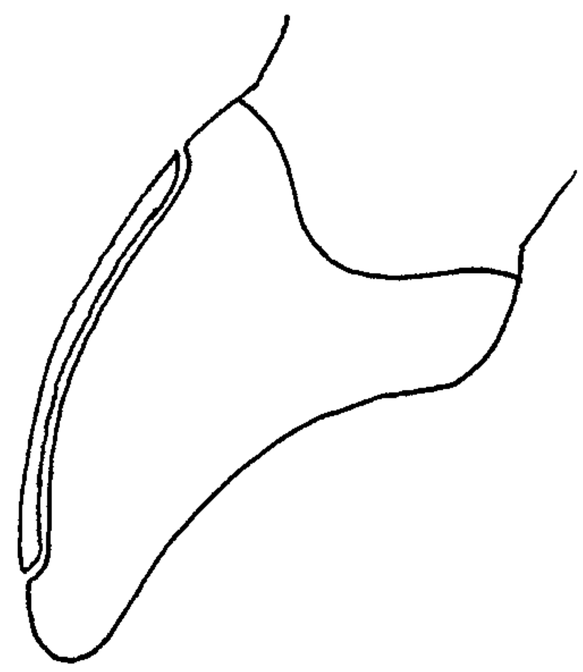
(a) No marginal gap or over/under-extension



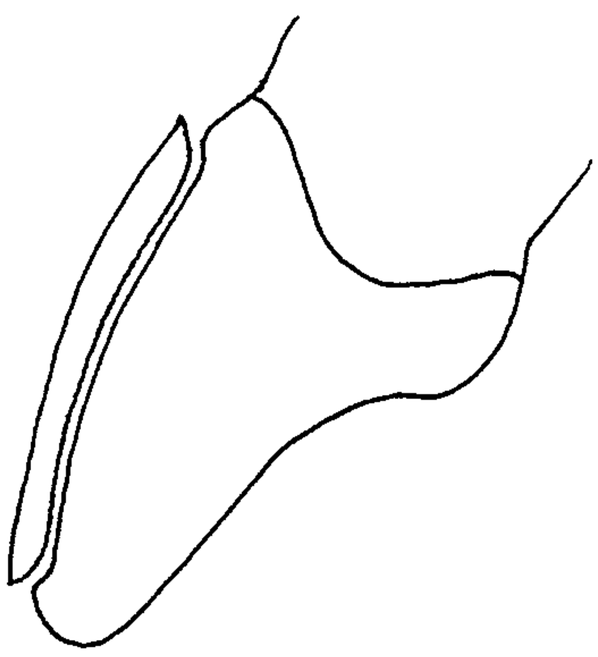
(b) No marginal gap, over-extension present



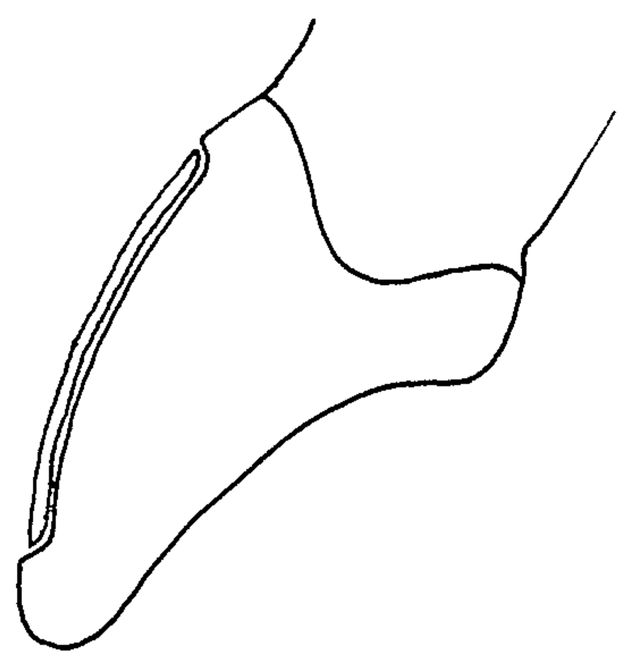
(c) No marginal gap, under-extension present



(d) Marginal gap with no over/ under-extension



(e) marginal gap with over-extension



(f) Marginal gap with under-extension

1.5.4 Factors affecting marginal adaptation

This review will be limited to the factors affecting the indirectly fabricated restorations (excluding indirect composite resins). A brief summary of factors affecting the marginal adaptation of indirectly fabricated restorations can be found in figure 1.5.3.

I. Clinical Stages

1. Preparation design and marginal adaptation

The design of the cavity preparation can affect the marginal adaptation of the restoration. Butt finishing lines are more favourable for porcelain restorations than chamfered margins. For example, Gavelis et al. (1981) found that the feather edge and bevelled design for the full gold crown preparation provided the best marginal seal, followed by the full shoulder, 45° shoulder, 90° shoulder with 30° and the 45° bevel. Ceramic restorations should have rounded internal line angles and enough bulk of material to minimize stress concentration because this can result in the fracture of the restoration.

2. Impression material and marginal adaptation

Silver plated dies fabricated from additional reaction silicone impression material have been found to produce more accurate crown margins than those fabricated by polyether, polysulphide or condensation reaction silicone impression materials (Crispin et al., 1984).

3. Issue stage

a. Cementation and marginal adaptation

The cementation procedure is a critical step for successful indirect restorations. The height and convergence of the axial walls, the diameter of the preparations, the presence of retentive channels and the type of cements are some factors which influence the fit of cast restorations (Ishikiriama, 1981). Ishikiriama found that cement painted in the part of the crown to be cemented gives a better fit than one which is completely filled with cement. Mechanical

vibration of the crown at cementation and venting or etching of the crowns also promote a better fit (Ishikiriama, 1981).

Chan et al. (1989) observed that cementation of a crown resulted in a marginal opening of at least the particle size of the luting agent. The marginal gaps after cementation were also proportional to the resistance from hydraulic forces and techniques used to overcome them (Davis, 1988).

Jorgensen (1960) suggested that any study aimed at determining the marginal adaptation of crown systems should be conducted under realistic conditions. Any studies which seat various crowns on the test dies without cementation will not correctly reflect marginal adaptation (Sorensen, 1990).

An excess thickness luting agent has been related to compromised marginal adaptation. Jorgensen (1960) found that marginal and gingival discrepancies due to the cement were determined by the average film thickness of cement and the factors influencing film thickness.

b. Seating pressure and marginal adapation

Increasing the seating pressure of a restoration was found to reduce the thickness of luting cement (Jorgensen, 1960). However, marginal adaptation of the restoration was unaffected (Weaver et al., 1991).

II. Laboratory Stages

1. Fabrication technique

Manufacturer's instructions must be followed, irrespective of the fabrication technique, so that the maximal adaptation of the restoration to the tooth preparation can be achieved. For example, the setting and thermal expansion of the investment in the Dicor® castable glass technique can cause distortion. Christensen (1966) and Belser et al. (1985) found that there was no significant difference between the margins of crowns fabricated by the platinum foil and cast metal margins. However, the margins of crowns formed with the platinum foil backing showed a significantly better fit than those formed with the direct lift technique (Cooney et al., 1985).

2. Effect of technique variables

The use of high energy mixing was found to interfere with the full expansion potential of a phosphate bonded investment by accelerating the setting reaction. The use of asbestos was important in mould expansion as it affected the casting size and ultimately, the marginal adaptation of the restoration to the tooth (Eden et al., 1979). Eden et al. (1979) also showed that the thickness of two layers of dry asbestos was approximately 20% greater than if they were wetted and lightly adapted. A delay in casting time has also resulted in an increase in casting size.

3. Types of die material used

Dental stones, plaster, electroformed silver and copper, epoxy resin, and refractory investment can be used as die materials (Craig, 1985). The type of die material selected depends on the purpose for which the die is intended. The desired qualities of these materials include accuracy, dimensional stability and high abrasion resistance (Craig, 1985). Some investigators found that silver plated dies were less accurate than stone dies. However, Toreskog et al. (1966) claimed that silver dies gave excellent clinical results. Crispin et al. (1984) in their study found that the marginal adaptation of crowns fabricated on silver plated dies was as accurate as, and, in some instances, even more accurate than those fabricated on stone dies.

4. Use of die spacer

The function of die spacer is to prevent the layer of cement from interfering with the complete seating of an otherwise precisely fitting casting (Eames et al.,1978). Weaver et al. (1991) found that the amount of die relief appeared to be a significant factor in the improvement of marginal adaptation. Eames et al. (1978) and Fusayama et al. (1964) also observed that castings made from relieved dies diminished the thickness of the luting layer and improved the marginal adaptation.

5. Waxing up

A wax pattern should be invested as soon as it is removed from the die to minimize any distortion. Care must also be taken when removing the wax pattern from the die. The act of

removing the wax pattern from a die with a shoulder margin has been found to cause an average opening of 35 micrometres before investing (Zeltser et al., 1985).

6. Investing

The correct powder to liquid ratio of the investment material must be strictly adhered to as this affects the hygroscopic and setting expansion of the investment. This would in turn affect the casting size and, finally, the marginal adaptation of the restoration.

7. Melting temperature of the alloy and marginal adaptation

Eden et al. (1979) found that alloys with higher melting points have a greater thermal differential between solidification and room temperature and exhibit greater casting shrinkage than alloys with a much lower melting point.

8. Metal coping fabrication and marginal adaptation

It has been observed that the largest change in the marginal adaptation occurs during the following four stages: metal coping fabrication, coping degassification, opacification and the formation of the all porcelain margin. This is due to the distortion of the metal coping during porcelainization and coping displacement during formation of all porcelain margin (Wanserski et al., 1986). Shillingburg et al. (1973) reported a change of 10.7 ± 7.1 micrometres in shoulder type marginal adaptation due to distortion during porcelainization.

9. Sintering and its effect on the margins

Mumford (1965) and Silver (1960) found that the fit of metal ceramic castings deteriorated during the firing of the porcelain veneer. This may be caused by:

a. Porcelain contraction (because of its different expansion properties from alloys).
b. Contamination of casting which reduces the melting temperature.
c. Grain growth of alloy.
d. Plastic flow of alloy.

e. Progressive reduction in resilience of metal caused by hardening and rigidity of porcelain.

f. Design of metal substructure.

g. Inadequate support of metal framework during firing.

10. Sandblasting

External grinding and internal sandblasting of crowns have been found to cause more marginal damage and generalized distortion of metal ceramic crowns than the thermal mismatch between porcelain and metal (Anusavice and Carroll, 1987).

Figure 1.5.3 Factors affecting marginal adaptation

Factors affecting marginal adaptation

Clinical Stages

1 Preparation design.
-definite finishing line

2 Impression material and technique.
-accurate reproduction of preparation, mixing and setting times, physical properties, correct base/catalyst ratio.

3 Issue stage.

i Type of cement used.
particle size, film thickness, consistency, mixing and setting times.

ii Seating pressure.

iii Venting of Crowns.

iv Polishing of restoration.

Laboratory Stages

1 Type of fabrication technique.
e.g. lost wax technique, castable technique, refractory or platinum foil technique.

2 Type of restoration to be fabricated.
e.g. ceramometal/ gold/ full ceramic crowns, porcelain/ gold/ composite inlays.

3 Type of die material used.
e.g epoxy die, type IV dental stone, silver plated die.

4 Care taken during fabrication to avoid chipped margins.

5 Use of die spacer.

6 Wax up--use of magnification, stress release in wax etc.

7 Investment--liquid/powder ratio, setting and hygroscopic expansion.

8 Burn-out temperature and its duration.

9 Casting--Type of alloy used, semi/non/precious.

10 Porcelain build up and sintering shrinkage.

11 Polishing.

12 Effect of sandblasting on margins.

1.5.5 Methods for determination of marginal adaptation

Numerous studies have been undertaken to study fit. These include vertical seating (Van Rensburg and Strating, 1984; Cooney and Caputo, 1981), internal adaptation (Strating et al., 1981), radiographic appearance (Christensen, 1966), clinical adaptability (Christensen, 1966), measurement of sectioned specimens (Gavelis et al.,1981) and measurement of specimens or replicas by direct visualization (Kusy and Leinfelder, 1977).

Mechanical devices, such as the tracing jig (Faucher and Nicholls, 1980), have been used to measure the relative distortion at the margin during porcelain firing cycles. Eden at al. (1979) evaluated fit as a percentage of casting size while rating scales have been used by Christensen (1966) and Sarrett et al. (1983). Kay et al. (1986) used a computer simulation study to analyse the effects of preparation design, die relief, and cementation factors.

Whichever method is chosen, the measurement of restorative marginal discrepancy should be consistent, reproducible and have standard points of measurement which are necessary for an impartial comparison.

There are basically two main methods for studying marginal adaptation:
in-vitro and in-vivo studies (Figure 1.5.4.).

In-vitro methods of studying marginal adaptation

I. Direct Methods

1. Direct viewing method

Direct viewing can be used to monitor stepwise distortion (Sorensen, 1990), to compare the firing distortion of various margin designs (Shillingburg, 1973), to measure the marginal distortion at each stage of the porcelain firing process (Wanserski et al., 1986; Anusavice and Carroll, 1987) and to assess the marginal fidelity of different types of crown systems. Unlike the cementation, embedment and sectioning method, the restoration used in the direct viewing method is not destroyed.

Figure 1.5.4 Determination of marginal adaptation

Determination of marginal adaptation

In-vitro methods

I. **Direct Method**

1. Direct viewing method

II. **Indirect Methods**

1. Optical methods
a. Scanning electron microscope
b. Video-enhanced measuring microscope with digital micrometer
c. Examination of rubber replicas

2. Mechanical method

In-vivo methods

I. **Direct Methods**

1. Direct viewing method
2. Endoscopic evaluation

II. **Indirect Methods**

1. Optical methods
a. Standard photographs
b. Scanning electron microscopy

2. Mechanical method

However, Sorensen (1990) noted several disadvantages of this method:

i. Repeated seating of the restoration on the master die can damage the margin by abrasion.

ii. There is difficulty in measuring and replacing the restoration accurately on the master die. This in turn increases the standard deviation and decreases the statistical significance.

iii. The rounded margin, examined microscopically, has no repeatable point of reference on the curved surface. However, Holmes et al. (1992) suggested in a situation like this, a point is chosen on that margin along a line bisecting the angle between the main contours of the die or casting.

iv. It is difficult to determine marginal overcontouring by direct viewing.

II. Indirect Methods

1. Optical method

a. Scanning electron microscope

The scanning electron microscope (SEM) can be used to either study the fit of a restoration on the extracted tooth without sectioning (Chan et al., 1989) or a rubber replica of the margin of the tooth (Cooney et al., 1985). However, viewing the teeth directly in the SEM produces artifacts in the marginal area due to the dessication of the samples (Lee and Swartz, 1970). Therefore, the replica assessment is a better method of choice (Roulet, 1989).

The advantages of the SEM technique are:

i. Evaluation is very convenient due to a wide range of magnifications available.
ii. There is an excellent depth of field.
iii. The widths of marginal openings can be obtained from the SEM photographs and scanning under the SEM allows view of the margin (Chan et al., 1989).

b. Video-enhanced measuring microscope with digital micrometer

Abbate et al. (1989) used a video-enhanced measuring microscope with a digital micrometer and image intensification on a high resolution television screen to compare the marginal fit of various ceramic crown systems.

c. Examination of rubber replicas of cement space under magnification

This technique involves the observation of rubber replicas of cement space between the tooth and the restoration without destroying the cemented crowns under magnification (McLean and Von Fraunhofer, 1971).

2. Mechanical method

a. Cross-sectional evaluation of margins under a microscope

This method measures the marginal fidelity by placing restorations on the dies which are embedded in resin, sectioned and subsequently viewed under a microscope. This method allows a greater precision in determining the degree of horizontal discrepancy (overcontouring) which is not possible with a direct viewing technique (Sorensen, 1990).

The disadvantages of this technique are:

i. Measuring marginal openings of sectioned specimens under a microscope is misleading as it gives the impression that the marginal openings are the same along the entire distance (Chan et al., 1989).

ii. The sectioned specimen which is used to measure the marginal opening may be cut in areas of a well fitting margin (Chan et al., 1989).

iii. The technique is time consuming because additional steps are required and the restoration is also destroyed.

In-vivo methods of studying marginal adaptation

I. Direct Methods

1. Direct viewing method

The in-vivo direct method of assessment of marginal adaptation involves instrumental probing, visual and radiographic examinations. This method is non-destructive, convenient and easy. However, discrepancies below 80 micrometres are difficult to detect under average clinical conditions (McLean and Von Fraunhofer, 1971). One disadvantage of this method is the inter and intra-examiner variations. Dedmon (1985) found that the inter-examiner variation was 51% and intra-examiner variation was 49%. Christensen (1966) also found that gaps of 119 micrometres gingivally were considered acceptable while interproximal and occlusal gaps of 26 micrometres were rejected by observers who probed the margins intra-orally.

2. Endoscopic evaluation

L'Estrange (1991) evaluated the margins of restorations clinically with an endoscopic microscope used with video recording facilities. This method offers accessibility and manoeuvrability, which are not available with the optical microscope and also allows high magnification, clinical examination and recording of the marginal fit of dental restorations.

II. Indirect methods

1. Optical methods

a. Standard photographs

This technique can be used to observe the external fit of the restoration. Sorensen (1990) devised a method of determining vertical and horizontal marginal discrepancies by taking photographs of margins and aligning them with plastic overlays to indicate the emergence profile. Photographic methods offer advantages such as:

i. An excellent discrimination can be revealed between small differences of marginal discrepancies.

ii. The longitudinal progress can be viewed at one time, the raw data is always available for future re-examination and multiple examiners are allowed for observation (Mahler and Marantz, 1981).

However, this technique is not suitable for the assessment of marginal discrepancies in composite resins. This is due to the lack of contrast between the tooth and the restoration (Roulet, 1989).

b. Scanning electron microscopy (SEM)

Impressions of the margins of restorations are taken and replicas in epoxy resin or stone are poured. These can then be observed under the SEM (Belser et al., 1985; Chan et al., 1989).

2. Mechanical method

This procedure involves the replication of the restoration, usually in stone or epoxy resin developed from rubber-based impressions. The silicone impression materials allow a resolution of one micrometre for marginal assessment (Kusy and Leinfelder, 1977). The limitation of this technique, and that of the photographic technique, is that the gingivoproximal area is not accessible for assessment (Roulet, 1989).

1.5.6 Marginal adaptation of restorations fabricated by the refractory die technique, the castable glass Dicor® technique and the CAD/CAM Cerec® technique.

Although theoretically, a marginal opening of about 25 micrometres can be assumed with the use of a cement which qualifies under ADA specification No. 8, measurement of the clinical situation is usually greater than the defined value (Gardner, 1982). McLean and Von Fraunhofer (1971) in their clinical study of 1000 restorations over a five year period concluded that 120 micrometres represented the maximum clinically acceptable marginal opening, whereas Holmes et al. (1992) suggested that the practical range for clinical acceptance of fit should be 50-100 micrometres.

Christensen (1966) proposed that the range of marginal opening acceptable for crowns with supragingival placed margins should be 2-51 micrometres and that for subgingival margins,

34-119 micrometres. However, most dentists would accept 70 ± 10 micrometres as a suitable marginal adaptation for complete veneer crowns (Weaver et al., 1991).

I. Marginal adaptation of restorations fabricated by the refractory die technique

1. Porcelain Veneers

Porcelain veneers made directly on refractory dies are less likely to warp and distort during the firing process. However, the marginal adaptation of veneers fabricated by this technique has not been found to be superior to that of the platinum foil technique. This could be due to the removal of the refractory material by sandblasting, which may damage the thin and delicate margins (Sorensen et al., 1992). Wohlwend et al. (1989) suggested coating the entire surface of the impression with 0.1 millimetre layer of fine quartz bonded investment material before filling it with refractory die material to aid easy removal of the veneer later on.

The marginal adaptation of refractory porcelain veneers ranges from 80 ± 40 micrometres (Sim and Ibbetson, 1993), 242 micrometres (Sorensen et al., 1992) to 400 micrometres (Tay et al., 1987). Harasani et al. (1991) found that the absolute marginal discrepancy of porcelain veneers ranges from 88-193 micrometres. McLean (1991) also found that the average gap is about 100 micrometres and the best possible marginal gap obtainable is 20 micrometres. It is obvious from the above few studies that the construction of accurately fitting veneers is difficult. This is because all porcelain powders have a volume porosity of 38-40% which makes shrinkage control difficult (McLean, 1988). It is also important to realize that the interpretation of marginal adaptation depends on the location and method of measurement.

2. Porcelain inlays

Thordrup et al. (1991) in a study found that the absolute marginal discrepancy for indirect porcelain inlays was 219 micrometres, while a mean marginal opening of 209 micrometres was reported by Sorensen et al. (1991).

II. Marginal adaptation of restorations fabricated by the castable glass Dicor® technique

1. Veneers

Sim and Ibbetson (1993) found that the marginal discrepancy of Dicor veneers at 0.5 millimetre thickness was 140 ± 60 micrometres and 180 ± 80 micrometres at one millimetre.

2. Crowns

The marginal discrepancy for Dicor® crowns ranges from 28 micrometres[42] to 65.3 micrometres (Abbate et al., 1989), while Weaver et al. (1991) and Davis (1988) found that the marginal discrepancy for Dicor® crowns was 57 micrometres and 46.6 micrometres respectively.

III. Marginal adaptation of restorations fabricated by the CAD/CAM Cerec® technique

1. Veneers

Cerutti et al. (1991) found that the in-vivo median marginal width of 15 Cerec® veneers varied from 95-225 micrometres, while Essig et al. (1991) found that the post-adaptation marginal gap of the veneers was 128 ± 12.5 micrometres and the pre-adaptation marginal gap was 248 ± 26.7 micrometres.

2. Inlays

The marginal gap of Cerec® inlays was found to range from 36 micrometres to 337 micrometres (Peters and Bieniek, 1991), while the absolute marginal discrepancy was 343 micrometres (Thordrup et al., 1991) with a mean marginal opening of 139 micrometres (Sorensen et al., 1991).

The wide range of measurements observed in the marginal adaptation of restorations fabricated by the three techniques, can be attributed to two main factors. Firstly, the method and location of measurement must be taken into consideration when comparing the marginal gap of one restoration with another. Secondly, the skills and experiences of the operator and technician are also important in ensuring the production of a well fitting restoration.

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[42] Dicor research report. Feb 1986 Vol. 2 Issue 1

1.6 The Bonding which makes Porcelain Veneers Possible

1.6.1 Historical background of bonding

It has always been the desire of the dental profession to pursue a restorative material which would adhere to tooth structure so that the two may function as one unit and withstand masticatory forces, microleakage and any insult from the oral environment.

This lack of adhesion of restorative materials and acrylic to tooth structure prompted Buonocore (1955) to explore the possibility of etching enamel. The concept of treating surfaces with acid to obtain better adhesion was not new, as this technique was earlier applied in industry to enhance the adhesion of paint and resin coatings to metal surfaces (Buonocore, 1955).

In his experiment, Buonocore found that adhesion produced by 85% phosphoric acid treatment was stronger and more lasting than that produced by phosphomolybdate-oxalic acid solution.

Since then, many workers have used 50% phosphoric acid solution buffered with 7% zinc oxide by weight as an etchant, prior to the bonding of sealants or composite resins to enamel. Silverstone (1974) used a series of different acid solutions to study the effect on human enamel in-vitro. Results showed that an unbuffered solution of 30% (w/w) phosphoric acid produced the most favourable condition for bonding.

The effects of acid etching on enamel (Buonocore, 1955; Silverstone, 1974)

1. The acid cleanses and removes plaque, surface and subsurface cuticles and chemically inert crystallites of enamel surface. This exposes a fresh, reactive surface with higher surface energy, which is more favourable for wetting, and therefore, adhesion.

2. There is also a selective dissolution of enamel, exposing the organic framework of enamel which serves as a network where restorative material can adhere.

3. The acid removes calcium salts, increasing both the size and the number of microspaces which allows the resin to penetrate and bond to the enamel. At the same

time, a new surface is formed due to the precipitation of new substances such as, calcium oxalate and organic tungstate complexes to which the restorative material may adhere.

4. The total surface area of enamel is also increased by the action of acid etching.

Silverstone et al. (1975) found that three basic types of etching patterns were produced when the enamel was etched.

Type 1: This etched pattern was the commonest amongst the three. It involved the preferential removal of prism cores.

Type 2: Prism peripheries were removed preferentially in this etched pattern.

Type 3: A combination of type 2 and type 3 etched patterns. The etched surface did not resemble enamel morphology.

These three patterns were all found to occur on a single tooth surface produced by an identical concentration of acid attack. On examination of the enamel-resin junction, it was found that resin tags of up to 50 micrometres in length were routinely identified.

The enamel surface etched with phosphoric acid appeared to be affected at three levels which can be described as three specific zones. The first zone , known as the "etched zone" refers to the narrow zone of enamel measuring approximately 10 micrometres in depth (Silverstone, 1975). The second zone is the qualitative porous zone which is about 20 micrometres in depth (Silverstone, 1975). The third zone is known as the quantitative porous zone which is 20 micrometres deep. It appears indistinguishable from sound enamel on qualitative examination and has also been rendered slightly porous as a result of acid solution. The level of porosity in this zone is very low and it is into this third zone that tags of resin extend from the enamel surface (Silverstone, 1975).

Etching and prismless enamel

There have been controversies over the prevalence of prismless enamel in deciduous teeth and the effect acid etching has on it (Silverstone, 1970). Silverstone (1975) found that a longer etching time of 120 seconds with 30% phosphoric acid on the deciduous teeth produced patterns that were similar to those found in permanent teeth. The reason is that deciduous teeth have a lower mineral content and a higher internal pore volume. This results

in the likelihood of the erupted deciduous surface enamel containing a larger amount of exogenous organic material than permanent surface enamel.

Prismless enamel is usually found near the cemento-enamel junction of the permanent dentition. A less than favourable retention pattern has been observed when the prismless enamel is etched (Martin and Bryant, 1984). This is due to the quality and the thinness of enamel present over this area.

1.6.2 Mechanism of bonding to tooth structure

Bonding refers to the attachment of one substance to another by a chemical attachment, or mechanical retention or a combination of both (Beech, 1982; Tyas et al., 1988) (Figure 1.6.1).

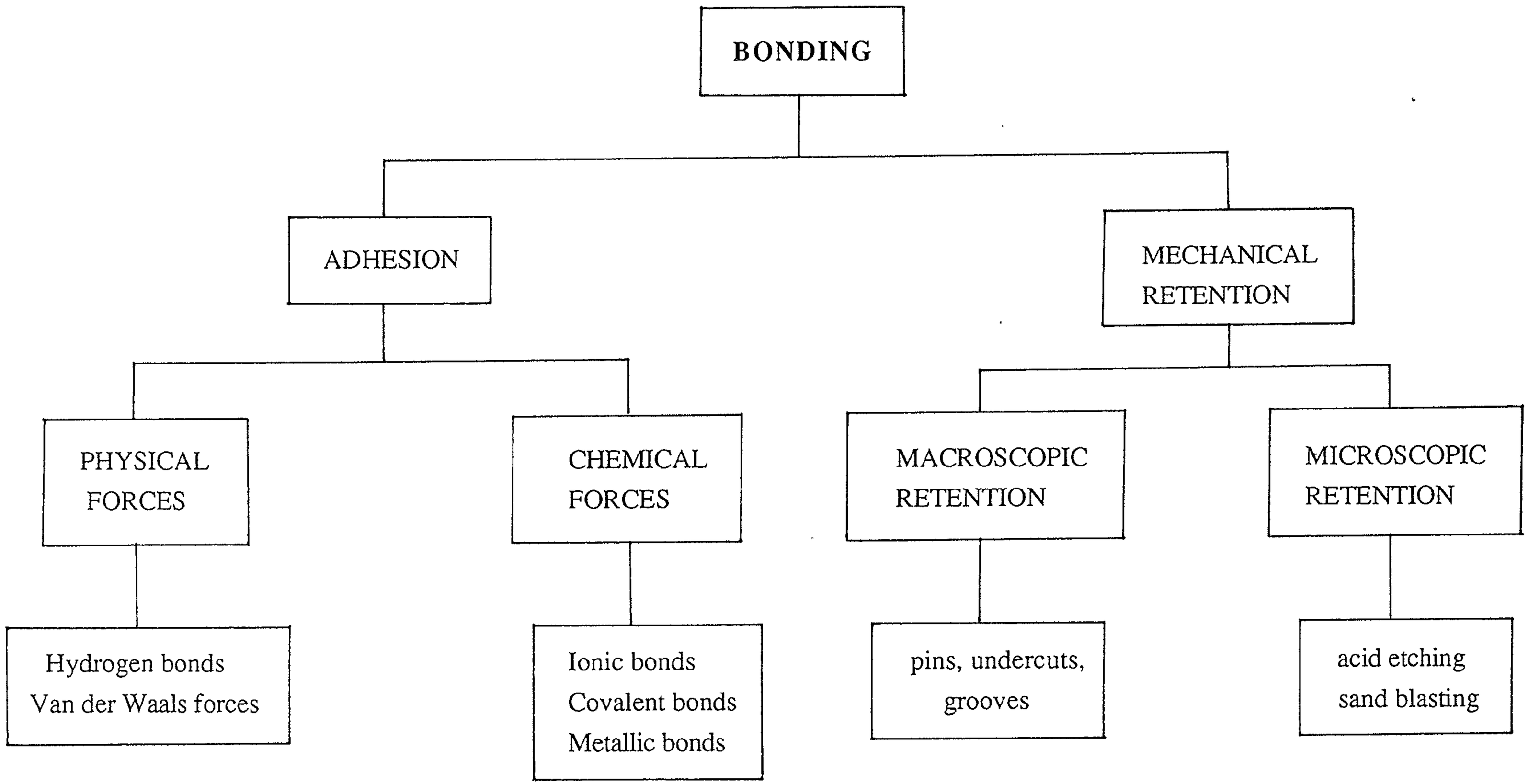
Mechanical retention

Mechanical retention can be achieved macroscopically via pins, grooves or undercuts while microscopic retention can be obtained via methods such as acid etching or sandblasting. (Figure 1.6.1).

Microscopic mechanical retention by acid etching involves the penetration of the bonding agent into surface irregularities. The acid removes the calcium salts from the enamel, increasing both the size and number of microporosities present, and allows the resin to penetrate into these surface irregularities to form "resin tags" within the enamel surface. This mechanical interlocking of the resin filaments increases the resin-tooth bond strength tremendously. Tag lengths from 20 to 50 micrometres have been routinely identified (Silverstone, 1975) depending upon factors such as, methodology of measurement, etching time, and the type of resin used. The fact that the resin tags extend into the third zone (quantitative zone) demonstrates that bonding occurs at a molecular level (Silverstone, 1975).

Acid etching has also been applied to ceramics and metal alloys for the mechanical retention of luting resin, as exemplified in ceramic veeners, inlays and Maryland bridges.

Figure 1.6.1 Mechanisms of bonding (adapted from Buonocore 1975)



Adhesion

Adhesion is defined as the force which causes the attraction of unlike molecules (Phillips, 1982). An adhesive is a substance capable of holding materials together by surface attachment. Adhesion can be obtained through physical forces or chemical forces (Figure 1.6.1). As a detailed description of the different forces in adhesion is beyond the scope of this literature review, only dentally related adhesion will be briefly discussed. The chemical forces involved in adhesion can be ionic, covalent or metallic (Buonocore, 1975b).

Some examples of adhesion by chemical forces are:

1. The adherence of glass ionomer cement and polycarboxylate cement to enamel apatite surfaces. This is achieved by hydrogen bonds provided by the free carboxyl groups from the acid. These are later replaced by metal ion bridges as the reaction continues.

2. The adherence of glass ionomer cement and polycarboxylate cement to dentine by hydrogen bonds between the amino groups of collagen and carboxyl groups of the acid. A metal ion bridge is also formed between the carboxyl groups of the acid and collagen in dentine.

3. The ionic bond formed between the silane coupling agent and the silica in porcelain.

4. The covalent bond formed between the coupling agent and composite luting cement.

5. Other examples include the bonding of porcelain to oxidized metal copings, bonding of dentine bonding agents to dentine.

Bonding with dentine

Bonding with dentine has been attempted with acid etching and dentine bonding agents. However, acid etching of dentine is not a favourable option due to the risk of pulpal irritation. Studies by Stanley et al. (1975) showed that pulpal reactions could arise from etching of dentine when the remaining dentine is less than one millimetre thick. Other histopathological studies showed that acid etching dentine did not cause adverse reactions (Inokoshi et al., 1982; Fujitani et al., 1986). The acid etch technique was found to be

ineffective for the adhesive bonding of restorative materials to dentine (Buonocore, 1975b) due to the heterogenous structure of dentine, its vitality and limited potential for microporosities. Dentine is also highly permeable to molecular flow and bacterial invasion with its wet surface caused by fluid seepage. This makes the bonding of a hydrophobic resin to this hydrophilic surface very complicated (Van Meerbeek et al., 1992). This led to the development of the dentine bonding agent in an attempt to enhance the bond between dentine and resin so as to decrease microleakage at the same time.

Dentine bonding agents are intended to form a chemical union between the dental tissue and the luting resin. They are composed of di- or multifunctional molecules. Each molecule has a dimethacrylate group to form a cross linkage with the monomer of overlying composite resin, and a functional group which interacts with the dentine surface to form a chemical bond (Sheth and Jensen, 1988; Retief, 1987). Although chemical interaction may play a role in creating the eventual bond, the current general tendency points to micromechanical retention as the principle form of attachment of resin to dentine (Söderholm, 1991).

There are two main types of dentine bonding agents. One type involves the removal of smear layer on the dentine. This is done by etching or conditioning the dentine to achieve better bonding. The other type depends on the smear layer retention for its bond. Preservation of the smear layer was thought to reduce dentine permeability and seepage of fluid out of the dentinal tubules. This dry surface created could then offer increased microporosities for bonding hydrophobic resin materials (Van Meerbeek et al., 1992). Most of the current dentine bonding systems use a conditioner to clean the tooth surface. The conditioner usually removes the smear layer, with the option of a primer to solubilize the smear layer, allowing the polymerizable bonding agent to interpenetrate the smear surface layer (Van Meerbeek et al., 1992).

The early dentine bonding agents were thought to involve either the inorganic or the organic constituents of dentine (Asmussen, 1985). A weak bond strength of 2-3 MPa was obtained by bonding the phosphate group of the adhesive to calcium in dentine. To counter the handicap of a wet bonding substrate, an aldehyde-based adhesive containing an aqueous mix of glutaraldehyde and HEMA known as GLUMA was developed. It is hydrolytically stable and a bond strength of 18 MPa has been reported (Asmussen, 1985).

1.6.3 Microleakage

As none of the present restorative materials truly adhere to tooth structure, except those systems based upon polyacrylic acid, a microscopic space therefore always exists between the restoration and the prepared cavity. Evidence of fluid and oral debris penetration along the interface of the restoration and cavity has been revealed by radioisotope tracers, dyes, and scanning electron microscopy, just to name a few (Phillips, 1982).

Microleakage can therefore be defined as "the clinically undetectable passage of bacteria, fluids, molecules or ions between a cavity wall and the restorative material applied to it" (Kidd, 1976). Microleakage has been shown to be related to marginal staining and breakdown, secondary caries at the tooth-restoration interface, post-operative sensitivity and pulp pathology (Phillips, 1982).

Factors affecting microleakage:

a. Differences in the coefficients of thermal expansion of the tooth and restoration

Significant differences in the coefficients of thermal expansion of the tooth and the restoration will cause the dimensions of space around the filling material to change as the tooth is subjected to temperature variations (Nelsen et al, 1952; Graver et al., 1990). This will also result in expansion or contraction of fluid in the space, as well as fluid exchange between the tooth and restoration. This gives rise to the rationale of subjecting specimens to thermocycling in microleakage studies to simulate clinical conditions which may stress the marginal seal (Bauer and Henson, 1984). The number of cycles used in thermocycling is still debatable. Crim and García-Godoy (1987) found that short term cycling appears to be as effective as protracted cycling whereas the clinical relevance of thermocycling has been challenged (Brännström, 1984; Trowbridge, 1987).

b. Polymerization shrinkage of the resin

Microleakage in composite restorations caused by polymerization shrinkage can be explained by the forces of contraction of the curing resin pulling the restorative material away from the tooth surface. This forms microscopic gaps which allow bacteria, oral fluid and debris to penetrate. Incremental placement of resin and the indirect method of fabrication have been suggested to overcome this problem (Douglas et al., 1989).

c. Method of restoration

Where indirect or direct methods of composite restoration are concerned, less microleakage was observed with the indirect method. This could be due to a more complete cure of the resin in the laboratory and the relatively thin layer of resin cement used in luting, minimizing polymerization shrinkage (Douglas et al.,1989). The use of cavity varnish underneath amalgam restorations has also presented with less microleakage compared with those where the varnish has not been used (Derkson et al., 1986).

d. Type of restorative materials used

Microleakage in composite resins was found to be greater than in amalgams (Derkson et al., 1986). The different types of composite resins also exhibited different microleakage patterns. Microleakage in microfilled resins is less than macrofilled resins. This could be explained by the fact that the microfilled resins have a lower modulus of elasticity and a higher water sorption property. These result in an expansion which offsets some of the curing shrinkage, thereby decreasing microleakage (Douglas et al., 1989).

e. Bond failure at restoration-tooth interface

Microleakage is a result of an inability of the restorative material to bond to tooth structure in such a way that a perfect seal exists between the two. In the cementation of restorations involving resin luting agents, if the bond strength between either interface (resin-tooth or resin-restoration) is strong enough to resist the polymerization shrinkage, gap formation can then be prevented (Tjan et al., 1989). It is therefore logical to assume that the weaker of the adhesive forces between the two bonding interfaces will fail. This will allow the dye molecules to penetrate the interfaces and displace the forces of attraction uniting the phases. For example, microleakage was greater along the resin-tooth interface compared to the porcelain veneer-resin interface (Sorensen, 1992; Harasani et al., 1991; Tjian et al., 1989) because the bond strength between the resin and etched silane treated porcelain was much higher, 22.4-24 MPa (Ibsen et al., 1987; Hsu et al., 1985), than the bond strength between resin and etched enamel, 13.8-20 MPa (Bowen, 1983).

f. Use of dentine bonding agent

Dentine bonding agents used in conjunction with composite resins are a deterrent to microleakage, but do not eliminate it. Although the third generation dentine bonding agents have greatly reduced contraction gaps at the tooth-restoration interface, the problem of

microleakage still exists. To overcome this, dentine bonding agents with greater bond strength to dentine and composite resins with reduced polymerization shrinkage should be developed (Retief, 1987).

Study of microleakage

Investigations of microleakage can be carried out both in-vivo and in-vitro, with the latter being more common. Some examples of in-vitro investigations include bacteria, dye, chemical or isotope penetration tests, electrochemical investigations, light microscopy, scanning electron microscopy and the use of compressed air. In-vitro experiments can either utilize a clinically relevant model, which attempts to reproduce the oral situation or simply test the materials' behaviour, which is of no clinical relevance (Taylor and Lynch, 1992). As a detailed description of the various methods of microleakage investigation is beyond the scope of this literature review, only the more common method of dye penetration test to be used in the experiment, will be discussed.

Dye penetration test

Dye penetration allows leakage to be shown in contrasting colours to both the tooth and the restoration without the use of hazardous chemicals and radiation as used in chemical and radioisotope tracer studies. The dye penetration test basically involves the immersion of extracted and restored teeth in a dye solution for a pre-determined period of time, followed by the washing and sectioning of the specimen and its examination under magnification to determine the extent of leakage around the tooth-restoration interface. Methylene blue and basic fuchsin are two of the most common organic dyes used in microleakage studies. Other dyes which can be used are crystal violet, fluorescein, Eosin, India Ink, Erythrosin, Blue Cresyl etc (Taylor and Lynch, 1992). The choice of dyes used has been on an ad hoc basis with little attention paid to the different sizes of dye molecules and their behaviour when used in these situations. Taylor and Lynch (1992) have also observed that while there is a wide choice of dyes available, individual researchers tend to use the same dye used by other researchers in areas of similar investigation.

As dye molecules are much smaller than bacteria, the marginal penetration of a dye is probably not an accurate measure of microleakage. However, severe dye penetration may indicate that the marginal gap is large enough to permit the entrance of bacteria (Graver et al., 1990).

The dyes used in dental research are usually manufactured in the form of solutions or suspensions of different particle sizes. Therefore, consistent results cannot be obtained, even when standardized techniques have been used.

The dye chosen should not have a particle size greater than the internal diameter of dentinal tubules (1-4 micrometres). It is also advisable to avoid the use of a dye which will bind to tooth substance or restorative material, as an area of stained dentine can be mistaken for a larger gap than it actually is. Colour stability is another criteria of the dye used in microleakage studies to allow accurate interpretation of results (Taylor and Lynch, 1992).

The significance of dye penetration has been questioned, as marginal leakage of dyes in laboratory studies is not a proof that restorations will fail clinically. In fact, most restorations are successful even though their margins can be penetrated by dyes (Graver et al., 1990).

The diverse methods of microleakage studies, with their advantages and disadvantages, have led to a lack of standardization. It then becomes difficult to make comparisons between similar techniques using slightly different apparatus, including the use of different dyes. Therefore, a standard technique using established materials and methods of assessment is essential so that accurate comparisons can be made between different studies.