THE USE OF COMPOSITE RESINS IN DIRECT ANTERIOR CROWNS

by

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PREFACE

This treatise consists of two chapters.

The first chapter reviews the principal materials used in the construction of direct composite resin crowns - composite resins. In particular, it attempts to examine their properties and the clinical implications of these properties.

The second chapter considers direct composite resin crowns. In particular it reviews the techniques used in their fabrication. The techniques are reviewed in the order in which they would be used during fabrication. Where relevant, the non-composite resin components of direct composite resin crowns are reviewed.

This treatise looks at history perhaps more than is customary. It is this author's belief that history not only teaches us about the past, but also helps us to understand the present, and to an extent may prepare us for the future.

The chapters, sections of the chapters, subsections of the sections and subsubsections of the subsections are numbered. These numbers are separated by full stops and placed in brackets, when the reader is referred to a particular section, subsection or subsubsection. For example: (1.5), (1.5.1), (1.5.1.1). These cross-references always contain a full stop, or full stops.

Numbers in brackets containing no full stops refer to products which are listed at the end of the relevant subsections, or sections if there are no subsections, in the order they are mentioned in the text. For example: (15). They contain the information given in the original references.

Tables and figures are placed at the end of the appropriate

subsections. There are two tables in the treatise. They are identified as Tab.1 and Tab.2. The figures are identified by the abbreviation Fig. and a number or numbers separated by full stops. For example: Fig.3 or Fig.3.3. The first number refers to the order in which the figure appears in the text, the second number (if used) to a particular sketch in the figure.

References to books, articles and lectures within the text contain the name(s) of their author(s), the year of publication or presentation and in the case of books the relevant page. The details are given in alphabetical order at the end of the treatise in the form indicated by "Guidelines for Authors" of the Australian Dental Journal 1990;35:81-4.

CONTENTS

Acknowledgements i
Preface ii
Contents iv
List of tables and figures vi
Introduction 1

CHAPTER 1. COMPOSITE RESINS

1.1 Definitions 2
1.2 History 5
1.3 Factors influencing properties of composite resins 10
1.3.1 Dispersed phase 10
1.3.2 Continuous phase 13
1.3.3 Interfacial phase 14
1.3.4 Polymerisation 15
1.4 Properties of composite resins 18
1.5 Clinical considerations 19
1.5.1 Physical and mechanical considerations 19
1.5.1.1 Dimensional stability 19
1.5.1.2 Thermal conductivity and diffusivity 21
1.5.1.3 Radiopacity 22
1.5.1.4 Strength and elasticity 22
1.5.1.5 Wear 23
1.5.2 Biological considerations 28
1.5.3 Aesthetic considerations 33
1.6 Classification of composite resins 38
1.6.1 Classification according to Lutz and Phillips 38
1.6.1.1 Traditional composite resins 38
1.6.1.2 Hybrid composite resins 39
1.6.1.3 Homogeneous microfilled composite resins 39
1.6.1.4 Heterogeneous microfilled composite resins 40
1.6.2 Classification according to Badenhorst and deWet 43

CHAPTER 2. DIRECT COMPOSITE RESIN CROWNS

2.1 Definitions 45
2.1.1 Crown 45
2.1.2 Direct composite resin crown 47
2.2 History 48
2.2.1 History of crowns 48
2.2.2 History of composite resin crowns 52
2.3 Sequence of steps in direct composite resin crown construction 61
2.4 Construction of direct composite resin crowns 62
2.4.1 Decision on whether a direct composite resin crown is indicated 62
2.4.1.1 General rule 62
2.4.1.2 Mechanical and physical requirements 62
2.4.1.3 Biological requirements 64
2.4.1.4 Aesthetic requirements 65
2.4.1.5 General considerations regarding indications 66

2.4.1.6 Characteristics and problems associated with different types of crowns according to the materials used in their construction 66
2.4.1.7 Advantages and disadvantages of the indirect technique of construction of crowns 70
2.4.1.8 Favourable characteristics of the direct composite resin crown 72
2.4.1.9 Unfavourable characteristics of the direct composite resin crown 73
2.4.1.10 Indications for a direct composite resin crown 73
2.4.1.11 Contraindications to a direct composite resin crown 74
2.4.2 Colour selection 77
2.4.2.1 Prophylaxis 77
2.4.2.2 Colour selection 77
2.4.3 Preparation of enamel 81
2.4.3.1 Extent of the preparation 81
2.4.3.2 Gingival margin 87
2.4.4 Varnishes and Bases 93
2.4.4.1 General considerations 93
3.4.4.2 Varnishes 95
3.4.4.3 Calcium hydroxide base 95
2.4.4.4 Zinc phosphate cement 96
2.4.4.5 Glass-ionomer cements 96
2.4.4.6 Zinc polycarboxylate cement 102
2.4.5 Pins 107
2.4.6 Post-cores 119
2.4.7 Etching 128
2.4.7.1 Etching of enamel 128
2.4.7.2 Etching of dentine 139
2.4.7.3 Etching of cementum 142
2.4.7.4 Etching of glass-ionomer cements 144
2.4.8 Bonding 150
2.4.8.1 General considerations 150
2.4.8.2 Bonding to enamel 152
2.4.8.3 Bonding to dentine 158
2.4.8.4 Bonding to cementum 168
2.4.8.5 Bonding to glass-ionomer cements 170
2.4.8.6 Bonding to composite resins 173
2.4.8.7 Bonding to porcelain 179
2.4.8.8 Bonding to gold 180
2.4.8.9 Bonding to amalgam 182
2.4.9 Placement and curing 189
2.4.9.1 Placement 189
2.4.9.2 Curing 196
2.4.9.3 Colour aesthetics 200
2.4.10 Finishing and polishing 204
2.4.10.1 Sealing the gingival margin 204
2.4.10.2 Finishing and polishing 206
2.5 Conclusions 216

Bibliography 217

LIST OF TABLES AND FIGURES

TABLES

Table 1. Physical and mechanical properties of composite resins 27

Table 2. Mechanical properties of materials used for bases 105

FIGURES

Figure 1. Ideals of feminine beauty 76

Figure 2. Restoration of cavities in the tooth which is to have a direct composite resin crown 106

Figure 3. Locations for the placement of pins 118

INTRODUCTION

Satisfactory restoration of anterior teeth is of great importance to the physical and mental well-being of patients. Often it can be achieved only through treatment using a crown or crowns.

A crown has to fulfil a number of requirements of a mechanical, physical, biological, and aesthetic nature. The materials used in the construction of the crown are among the factors that determine the degree to which these requirements can be fulfilled.

One of the most exciting developments in the field of Operative Dentistry in the second half of the 20th century has been the advent of composite resins, their continuous evolution and their use in adhesive dentistry.

This treatise is intended to describe the materials and techniques used in the construction of the direct composite resin crown. An attempt will be made to evaluate the answers the direct composite resin crown provides to some problems, and to examine the new problems it poses.

CHAPTER 1

COMPOSITE RESINS

1.1 DEFINITIONS

The word "composite" according to the Macquarie Dictionary (1981, p. 389) has 4 meanings. The one relevant for this treatise is: "made up of various parts or elements". The relevant meaning of the word "resin" is: "The name given to a group of solid or semi-solid amorphous substances of complex nature." (Butterworths Medical Dictionary, 1978, p. 1461).

In dentistry, composite resins (also called only "composites") may be defined as tooth coloured restorative materials which set through polymerisation and which consist of three essential components: a resin binder, a filler and a coupling agent (Phillips, 1982, p. 224).

The resin binder is also referred to as resin matrix, organic matrix, organic phase, matrix, continuous phase, dispersion phase, reinforced phase, and even matrix phase. Most often it is based on BIS-GMA monomer synthesised by Bowen. However, there are several composite resins with the continuous phase based on different compounds, such as modified BIS-GMA (without hydroxyl groups), urethane diacrylate, etc. The continuous phase also contains diluents, or viscosity controllers (to reduce the high viscosity of the BIS-GMA), inhibitors (to prevent premature polymerisation),

initiators (which when activated initiate the polymerisation), activators (which activate the initiators), ultraviolet light stabilisers (to improve the colour stability), and pigments (to modify the colour of the composite resin).

The filler is also called particles, interrupted phase, dispersed phase and reinforcing phase. The particles differ in size. Originally they were of quartz, borosilicate glasses or ceramics and ranged from 5 to 30 micrometres, although more recently their size has been reduced to 1 to 5 micrometres. These are the particles of the macrofilled or conventional (or traditional) composite resins. The particles of microfilled composite resins are either colloidal or pyrogenic silica (silicon dioxide), and range from 0.04 to 0.1 micrometres. The so called hybrid composite resins contain both kinds of particles.

The coupling agent is also called the keying agent and interfacial phase. Usually organosilanes are employed as coupling agents, and they bond the inorganic particles to the organic matrix.

Polymerisation is a series of chemical reactions by which the macromolecule, or polymer, is formed from large numbers of single molecules known as monomers. The exact mechanism of polymerisation is still somewhat obscure, but it is accepted that it occurs when monomer molecules become activated through the opening of double bonds between atoms of carbon. An activated molecule of monomer then "collides" with another molecule of monomer, forms a covalent bonding with it, and activates it in the process. The monomer molecules become activated by energy transfer from another activated compound - the initiator - which has been activated either by heat,

chemically, or by light (ultraviolet or visible.) Theoretically, the chain reactions of the polymerisation should continue until all of the monomer has been used up. In practice, the polymerisation is never total.

(Bowen, 1979; Craig, 1981; Phillips, 1982, p. 159, 162, 223-7, 233; Lutz and Phillips, 1983; Marzouk, Simonton and Gross, 1985, p. 170-1; Wilson, 1988).

1.2 HISTORY

There is no evidence that in the ancient world carious teeth were restored.

The Ebers papyrus contains prescriptions for mixtures to be pressed into a (presumably carious) tooth, but judging from their composition these were no more than ephemeral dressings. Although some of them contained resin (terebinthenic), they also contained, somewhat disturbingly, honey or a purgative (Hoffmann-Axthelm, 1981, p. 22).

The bronze wire implanted into the root canal of an upper right lateral incisor found in the Negev Desert and dating to the Hellenistic period (ca 200 BC) may be the earliest known example of a metal object filling a tooth, albeit probably based on a "'toothworm' theory" of dental disease (Zias and Numeroff, 1987).

Roman encyclopaedist Aulus Cornelius Celsus (born ca 25 BC - died ca 50 AD) recommended filling a cavity with well fitting lead (bene adcomodato plumbo), but this was only so that the tooth did not break when grasped by forceps (Hoffmann-Axthelm, 1981, p. 70). It is interesting to note, however, that the word for "filling" in many European languages sounds like "plomber" (although it may be spelled differently). This is undoubtedly based on Latin, even though the word was coined in France, in the 19th century (ibid., p. 287).

The Mayas of Central America in their Classical period (ca 300-900 AD) placed circular inlays made of semiprecious stones (turquois, jade, jadeite, etc.) in the labial surfaces of anterior teeth. The cavities were prepared by using the bowdrill (Fastlicht,

1976a). Circular cavities filled with reddish material were also found. They were either filled with this material originally, or it was used to replace lost inlays. The material was presumably placed into the cavities in a plastic condition and later hardened. It is assumed to have contained powdered pyrite or markesite, mixed with an unknown substance (Fastlicht, 1976b, p. 97-8).

At approximately the same time, in China, Su Kung in his Materia Medica (659 AD) mentioned amalgam as "silver dough" (Hoffmann-Axthelm, 1981, p. 43). In Europe, in the German region, amalgam was first mentioned by Johannes Stockerus in 1528 (ibid., p. 157). However, amalgam began to be used widely only in the 19th century, when it replaced lead, which was generally used to restore cavities (ibid., p. 287).

The acceptance of amalgam was neither immediate nor universal, and indeed the "amalgam war" lasted into the second part of the 19th century (ibid., p. 289). Even though amalgam won, it has never been particularly popular for the anterior teeth, owing to its appearance. The available alternatives - gold inlays, or gold foil restorations - while at the time aesthetically acceptable, were both time consuming in construction, and expensive.

Considerable efforts were made to develop cheap alternatives to amalgam, and during the mid 1850's zinc oxychloride, magnesium oxychloride and zinc oxysulfate appeared. Unfortunately, all of these were found to be highly irritating to the pulp, were too opaque, and generally did not withstand the oral environment (Peyton and Craig, 1971, p. 398). Zinc phosphate cement, introduced in 1879, proved more acceptable (ibid., p. 12). However, while zinc phosphate restorations were less damaging to the pulp, they too were soluble

in oral fluids and lacked translucency.

After a tentative start in the last century, silicate cement began to be used early in this century, and was firmly established by the 1940's (Jackson, 1971). Its use, however, has always been controversial, its main shortcomings being: contraction resulting in poor marginal adaptation, solubility which appears to be inherent in its system and toxicity, which was at first attributed to the possible presence of arsenic (Peyton and Craig, 1971, p. 416) and then to its low pH (Castagnola and Garberoglio, 1972). To this needs to be added its sensitivity to dehydration throughout its life (Phillips, 1982, p. 486) and its brittleness which Bowen (1963) attributed to its low tensile strength. The cement was used basically only because no satisfactory alternative existed.

Such an alternative became available during World War II, when direct filling resins were developed. These are based on poly (methyl methacrylate), which had been used in dentistry prior to that, for the fabrication of dentures and also of "acrylic crowns".

Unfortunately, once again the first rush of enthusiasm was followed by disappointment. The material appeared toxic to the pulp. This was attributed at first to the amine activators, and later to the "lethal effects of the acrylic monomer" (McLean, 1951).

Nor are the physical and mechanical properties of the unfilled acrylic direct filling resin satisfactory. It suffers from polymerisation shrinkage of about 7% vol. (Phillips, 1982, p. 219), and its linear coefficient of thermal expansion is more than 8 times that of the hard dental tissues (ibid., p. 220). The resin is not hard enough, its KHN (Knoop Hardness Number) being only 15 as against 65 for dentine and 300 for enamel (ibid., p. 221), its

modulus of elasticity is too low, being about 2.4 GPa (ibid., p. 219) as against 16.6-18.7 GPa for dentine (Craig and Peyton, 1958) and 78-96 GPa for enamel (Craig, Peyton and Johnson, 1961) and its compressive strength is also much lower than that of the tooth structures, being 69 MPa (Phillips, 1982, p. 219) as against 218.8-306.9 MPa for dentine and 95.1-290.3 for enamel (Stanford, Weigel, Paffenbarger and Sweeney, 1960).

Modifications were obviously needed, and in the late 1950's development of composite resins began (Bowen, 1958). A material with improved properties was produced by incorporating vinylsiloxane treated silica particles into an organic polymer which was primarily the addition reaction product of bisphenol A and glycidyl methacrylate and which has since been referred to as "BIS GMA" (Bowen, 1963).

Since then, the development of composite resins has been phenomenal. A computer search through the Australian Medline Network (drawing on some 455 dental journals worldwide) reveals the following number of articles dealing in a substantial way with composite resins (articles in the English language, or articles with English abstracts):

1966-1971.....7

1972-1976.....373

1977-1979.....479

1980-1982.....461

1983-1985.....896

1986-1987.....625.

A milestone in the history of the composite resins was the introduction of the "command setting", in 1972, where the

polymerisation was initiated by UV light (as against the original chemical initiation), and later (1978) by visible light (Atmadja, 1986).

Another important development was the introduction in 1976 of the microfilled composites (Van Dijken, 1986) with their superior aesthetic properties. However, as some physical and mechanical properties of the microfilled resins are inferior to those of the conventional composite resins, efforts were made to combine the good qualities of both. This lead to the development of the so-called hybrid composite resins, which became available from 1979 (ibid.).

In 1987 the total number of composite resin systems on the market was over 150 (Badenhorst and deWet, 1987). New systems were - and are - appearing continually. By the time the clinical performance of a material can be adequately assessed, it is superseded by a new material (Editorial comment, 1986; Bryant, 1987).

That perhaps is the price of progress. It does, however, make it more imperative than before for the practitioner to understand the explanation and significance of different properties, to know what can be expected of different types of composite resins and, to an extent, to know how the changes in materials and techniques are likely to affect clinical performance.

1.3 FACTORS INFLUENCING THE PROPERTIES OF COMPOSITE RESINS

1.3.1 Dispersed phase.

Composite resins with large particles (over 10 micrometres) cannot be polished (Phillips, 1982, p. 231; Lutz and Phillips, 1983, Jordan and Gwinnett, 1988, p. 14). The particles are harder than the organic matrix, which gets abraded away during the finishing procedures. Either the particles are left standing above the surface, or they get plucked off, resulting in either case in a rough surface. This may lead to surface staining and plaque accumulation (Lutz and Phillips, 1983).

Plaque in its turn may cause surface softening, which contributes to surface staining and increased wear (Asmussen, 1984; Asmussen and Hansen, 1986). Primarily, however, it is the plucking (Phillips, 1982, p. 232; Lutz and Phillips, 1983), as well as straining, of the resin matrix around the particles (Leinfelder, 1987) which is responsible for the poor wear resistance of the macrofilled composite resins.

The smaller the particles, the better the polishability (Lutz and Phillips, 1983; Wilson, 1988). When the particles become smaller than the wavelength of visible light (approximately 0.4 to 0.7 micrometres), the polish has the potential to be permanent, because even if the particles are lost, the irregularities cannot be detected optically. The rate of wear decreases with decreases in the size of the particles (Lutz and Phillips, 1983; Leinfelder, 1987), since the smaller particles provide less purchase for the plucking forces.

Unfortunately, a decrease in the size of the particles tends to force a reduction in the concentration of the particles, as the viscosity of the continuous phase rises with increases in the total surface area of the dispersed phase. The total surface area of the dispersed phase, for the same concentration of the dispersed phase, increases with the decreasing size of the particles. For example, colloidal silica has a surface area of up to 300 square metres per gram (Craig, 1981). And since it is the filler, which turned the unfilled resin into a composite resin, in many of their physical and mechanical properties the microfilled composite resins fall in between the unfilled resins and the macrofilled (conventional) composite resins.

The importance of the concentration of the filler (loading) can be seen from a series of in vitro tests carried out by St. Germain, Swartz, Phillips, Moore and Roberts (1985). They found that for microfilled resins increased filler loading meant increased depth of cure, increased colour stability, increased hardness, increased compressive strength, increased stiffness and decreased water sorption. It also meant decreased resistance to toothbrush abrasion and wear with hydroxyapatite. However, while one always needs to be careful in interpreting the clinical significance of in vitro experiments, this is especially so as far as interpreting wear tests is concerned, as wear is an extremely complex process. Similar tests were carried out with similar results by Li, Swartz, Phillips, Moore and Roberts (1985) on composite resins filled with particles 2 and 15 micrometres large (that is with macrofilled composite resins).

Other than the size of the particles and their concentration,

the following characteristics of the particles have an important influence on the properties of composite resins:

The hardness of the particles - if the hardness decreases, the wear resistance may increase, as the masticatory stresses will be absorbed by the particle, rather than transmitted onto the matrix (Leinfelder, 1987). This view is also held by Marzouk, Simonton and Gross (1985, p.171), who stated that the newer versions of their first generation materials, with "smaller, softer, more rounded particles" would wear less.

However, Draughn and Harrison (1978), who studied "abrasive wear" of seven composite resins in vitro, obtained the highest abrasion rate with Nuva-Fil (1) containing "comparatively small and soft particles", and the lowest with Adaptic (2) "characterised by many large particles with sharp edges". This only goes to show that in vivo wear is a complex process. While rounder particles may improve the wear resistance, coarser particles increase the modulus of elasticity (Bryant and Mahler, 1986).

Finally, particles can provide radiopacity if they contain heavy metals, such as barium (Barness and Kidd, 1980; Lutz and Phillips, 1983).

PRODUCTS:

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

(2) Adaptic. Johnson & Johnson, New Brunswick, NJ, USA.

1.3.2 Continuous phase.

This is the phase responsible for polymerisation contraction. Asmussen found (1975) that the greater the content of diluents in the matrix, the greater the polymerisation contraction and, of course, the lower the viscosity of the composite resin. Higher BIS-GMA content also tends to reduce the internal discoloration (Asmussen, 1985). It has also been found (Asmussen, 1984; Asmussen and Hansen, 1986) that the matrices containing higher concentrations of TEGDMA (a diluent monomer) were more resistant to softening caused by ethanol and plaque acids. This softening, which unfavourably influences the wear resistance and increases surface staining, would obviously be more associated with alternative life styles. The continuous phase is also of importance when a composite resin is bonded to a composite resin. If the matrices differ, the bonding strength may be adversely affected (2.4.8.6).

1.3.3 Interfacial phase.

This phase is the weakest link in the whole system (Bowen, 1979; Marzouk, Simonton and Gross, 1985, p. 172). Organosilanes are employed as the coupling agents. Those reinforcing fillers which present an alkaline environment in water (such as barium glasses), can degrade the attachment of the coupling agent (Bowen, 1979; Craig, 1981) resulting in increased leaching. In the microfilled composite resins containing prepolymerised complexes, the bond between the resin matrix and these complexes is polymeric in nature and is the main reason for the technique sensitivity of these materials, as it can be fractured by the finishing instruments (Lutz and Phillips, 1983).

1.3.4 Polymerisation.

The initiator of the polymerisation may be activated in three ways (Craig, 1981; Phillips, 1982, p. 226; Marzouk, Simonton and Gross, 1985, p. 170):

Activation by heat. The initiator (benzoyl peroxide) decomposes at temperatures over 60 degrees Celsius, forming free radicals which activate the molecules of the monomer.

Activation by another compound. This is also referred to as chemical cure. The chemically-activated composite resins require at least two components - usually two pastes - one component containing the initiator (benzoyl peroxide), the other the activator (tertiary aromatic amine). Upon mixing the components together, the initiator comes into contact with the activator and forms free radicals.

Activation by light. This was originally ultraviolet light (UVL). The activator (alkyl benzoin ether) upon exposure to UVL decomposed and formed free radicals. The newer composite resins, activated by visible light (VL), contain an initiator (diketone) which absorbs photons from the VL of about 470 nanometres wavelenght - blue in the hue - and in conjunction with the activator (tertiary aliphatic amine), forms free radicals.

Although heat cure achieves maximum polymerisation, this method is unfortunately not feasible for direct composite resin crowns. However, heat cure is used by manufacturers to fabricate the prepolymerised microfilled complexes used to increase the filler loading of some microfilled composite resins (Lutz and Phillips, 1983). Heat cure may also be used as a secondary cure for composite resins cured by light, or chemically, in order to improve some of

their characteristics (Bausch, de Lange and Davidson, 1981; Wendt, 1987a; Wendt, 1987b; Leinfelder, 1988; Wendt, 1989; Kanca, 1989).

Light curing achieves better polymerisation than chemical curing (although not as good as heat curing) and also has the following advantages:

a. The polymerisation does not start until the light is applied. It gives the operator adequate time for the placement and shaping of the restoration. (However, the time is not unlimited, as even daylight may bring about polymerisation. Therefore, the material should not be removed from the container prematurely.) This means there will be less time needed for the finishing of the restoration. It also saves material, as the excess is likely to be smaller.

b. Light curing does not require mixing. If a composite requires the mixing of two or more componenets for its cure, air might be entrapped which inhibits polymerisation. The entrapped air can also cause aesthetic problems (Phillips, 1982, p. 165-6, 229; Leinfelder, 1985) not associated with light curing.

c. Once the light curing starts, the hardening of the material is more rapid than that occurring during the chemical cure. This, as well as the fact that the hardening starts from the surface, reduces the danger of disturbing the restoration while only partly cured, which could jeopardise the retention and the strength of the restoration, as well as the quality of its surface. The fact that the restoration hardens from the surface, however, is a mixed blessing, as it inhibits the inflow of material from the free surface, which otherwise would tend to reduce the magnitude of the shrinking stress (Feilzer, de Gee and Davidson, 1987) and the

wall-to-wall gap caused by the polymerisation shrinkage (Asmussen, 1975).

d. The light-cured composites are more colour-stable than the chemically-cured composites. The internal discoloration of chemically-cured composites is attributed to the oxidation of the excess aromatic amine in the cured polymer. This amine is not necessary in the light-cured composite resins, although some brands may contain it to enhance the level of polymerisation (Asmussen, 1985).

When compared with the UVL-activated composites, the VL-activated composites have the advantage of a greater depth of cure. The VL, unlike the UVL, can activate the initiator through the enamel. (Craig, 1981; Phillips, 1982, p. 226; Jordan and Gwinnett, 1988, p. 18-21). While the enamel does inhibit the transmission of VL with a resulting reduction of polymerisation, this may be compensated for, to some degree, by an increase of the curing time (Standlee, Caputo and Hokama, 1988).

1.4 PROPERTIES OF COMPOSITE RESINS

The collective reactions of atoms, whether physical or chemical, determine the effectiveness of the material (Phillips, 1982, p. 10).The collective reactions of the atoms (usually combined into molecules) in a particular way, under particular conditions can be described as a property of the material. The properties of a material determine its behaviour in clinical situations.

However, one has to be prudent in extrapolations, as clinical situations tend to be very complex.

Table 1 gives a number of the physical and mechanical properties of composite resins. For comparison, the same properties of dentine and enamel are also given, where applicable.

Generally speaking, restorative materials with properties closely matching the properties of natural tissues can be expected to make better restorations than those with different properties.

1.5 CLINICAL CONSIDERATIONS

1.5.1 Physical and mechanical considerations.

1.5.1.1 Dimensional stability. It is an inherent property of restorative resins that they contract during polymerisation (Asmussen, 1975).

While methyl methacrylate shrinks during polymerisation about 22% vol., the shrinkage during the polymerisation of a composite resin is reduced. This is because the BIS-GMA is a larger molecule than the methyl methacrylate molecule. Further reduction is achieved by the incorporation of the filler. Bowen (1963) found the addition of the filler reduced the "hardening shrinkage" to 2.7% vol.

The reduction of shrinkage obtained by increasing the amount of the filler may not necessarily reduce the size of the contraction gap between the restoration and the tooth. Asmussen (1975) found that this contraction gap did indeed depend on the matrix (and primarily on the amount of the diluent - positive correlation), but that the addition of the filler did not decrease the gap. It was thought that the filler caused an increase in the viscosity, which prevented the flow of the material from the free surface into the cavity and in doing so cancelled the effect of the reduction in the polymerisation shrinkage.

From this it would follow that if the concentration of the filler was increased, but the viscosity of the material was not (or at least was only to a lesser degree), then the wall-to-wall contraction gap should be reduced. Indeed, this was shown to be so by Munksgaard, Hansen and Kato (1987).

Like all materials, the composite resins are subject to thermal dimensional changes. As their coefficient of thermal expansion differs considerably from that of natural dental tissues (Tab. 1), the width of the gap changes with changing temperatures. This should be particularly detrimental at lower temperatures, when the width of the gap tends to increase. However, only small changes in the gap have been detected (Staninec, Mochizuki, Tanizaki, Fukuda and Tsuchitani, 1986; Torstenson and Brännström 1988a).

This gap has been found to average 13 to 43 micrometres in cavities 4 mm in diameter (Exner and de Wet, 1987). Torstenson and Brännström (1988b) found a range from 7.1 micrometres for a conventional composite resin (1), to 20.9 micrometres for a hybrid composite resin (2) in cavities "about 3 mm in width", when the excess material was removed with a sharp instrument. Torstenson and Brännström (1988a) found that the application of a hot potato (75-85 degrees Celsius) to the specimen decreased the mean width of the gap by only 1 micrometre, while ice cream from the freezer (<0 degrees Celsius) increased the mean width of the gap by 4-7 micrometres (cavities 3 mm wide).

Composite resins are subject to water sorption, due partly to their porosity, partly to the polar properties of the resin matrix molecules. Water sorption leads to hygroscopic expansion. The greater the filler loading, the smaller the water sorption and the expansion (Asmussen, 1985; St. Germain, Swartz, Phillips, Moore and Roberts, 1985; Li, Swartz, Phillips, Moore and Roberts, 1985; Oysaed and Ruyter, 1986; Exner and de Wet, 1987).

Asmussen (1985) recommended hygroscopic expansion as a means of eliminating the marginal gap, and recommended that the margins of

the restoration not be polished for several days, lest the debris from the polishing be forced into the gap and prevent its closure. However, the benefits of hygroscopic expansion are not uncontroversial. While most of the expansion occurs within two weeks, equilibrium is reached after about 8 weeks (Pearson, 1979). In that time bacteria may penetrate into the gap, although this may be reduced by the outward flow of the dentinal fluid (Stuever, Goldberg and Gross, 1971; Johnson, Olgart and Brännström, 1973). Water also causes hydrolytic degradation of the composite resins (Söderholm, Zigan, Ragan, Fischlschweiger and Bergman, 1984; Oysaed and Ruyter, 1986; Calais and Söderholm, 1988).

A better way of dealing with the contraction gap seems to be the sealing of this gap with a low viscosity unfilled resin (Torstenson, Brännström and Mattsson, 1985; Kemp-Scholte and Davidson, 1988).

1.5.1.2 Thermal conductivity and diffusivity. The thermal conductivity of the composite resins, as well as their thermal diffusivity (Watts, Haywood and Smith, 1983; Craig, 1989, p. 52, 262), appear to match fairly closely that of the natural dental tissues. Yet it is a known fact that teeth filled with composite resins may promptly react to a drop in temperature. This is thought to be the consequence of the outflow of fluid through the dentinal tubules, into the contraction gap, owing to capillary action (Torstenson, Brännström and Mathson, 1985). This further points to the desirability of sealing the marginal gaps.

Some highly filled composites (1, 3, 4) have exhibited rates of thermal conductivity and diffusivity up to three times higher than

that of dentine (Brady, Lee and Orlowski,1974; Watts, Haywood and Smith, 1983; Watts, McAndrew and Lloyd, 1987.) The clinical significance of this, however, may not be great, as, by comparison, the thermal conductivity of amalgam is more than thirty six times greater and its thermal diffusivity more than fifty two times greater than those of the dentine (Craig, 1985, p. 48, 50).

1.5.1.3 Radiopacity. Radiopacity is achieved by the addition of heavy metal (such as barium, strontium, etc.) salts (Barness and Kidd, 1980; Phillips, 1982, p. 226). Generally speaking, the radiopacity of composite resins is often insufficient for radiographic examination, and this is especially true of the microfilled composites.

Craig (1981) stated, "Because the microfilled composites contain silica it is also apparent they will not be radiopaque".

However, Stanford, Fan, Schoenfeld, Knoeppel and Stanford (1987) evaluated the radiopacity of eleven light-cured composite resins and found them more radiopaque than the dentine, although mostly less radiopaque than the enamel. They included in their study microfilled composite resins, which were found to be somewhat radiopaque. Radiopaque substances are now being added even into the microfilled composite resins.

1.5.1.4 Strength and elasticity. It can be seen from Tab.1 that the composite resins are not markedly inferior to the natural dental tissues in compressive strength (and that the microfilled composite resins are stronger in this regard than the conventional ones). However, according to Asmussen (1985), this has no documented

clinical significance, and, indeed, even in the posterior heavily stressed occlusal surfaces one does not see an occlusal composite resin restoration crushed (provided it is resting on a sound base).

As shown in Tab.1, the tensile strength of composite resins is inferior to that of the dentine (and the microfilled composite resins are inferior in this regard to the conventional ones). Once again, Asmussen (1985) considered it irrelevant from the clinical point of view. However, this position is more controversial. In clinical situations, there are usually combinations of forces at work, and the lower tensile strength of the microfilled composite resins, together with their lower transverse strength (Bryant and Mahler, 1986), and with their lower fracture toughness (Lloyd and Iannetta, 1982) seems to be responsible for the higher susceptibility to fracture of the microfilled composite resins (Lambrechts, Ameye and Vanherle, 1982).

Bryant and Mahler (1986) also studied the elastic modulus of 13 composites and found it comparatively low, ranging from 4.5 GPa (7) to 18.8 GPa (8), with the microfilled composites at the lower end of the range. The low elastic modulus is thought to be responsible for sensitivity, as an excessive bending of a restoration may lead through "pumping action" to a development of hydraulic pressures in the pulpal fluids (Bryant and Mahler, 1986; Fusayama, 1987).The low elastic modulus, particularly of the microfilled composite resins, is thought by Leinfelder (1987) to be one of the factors contributing to localised wear and also to bulk fractures of microfilled composite resins restorations.

1.5.1.5 Wear. All composite resins, when in function, are

subject to a loss of material from their surface - a property called wear. Wear leads to a loss of anatomical form, and may result in reduced masticatory efficiency, over-eruption and tilting of teeth, premature contacts and occlusal interference, and the potential for an accelerated loss of vertical dimension (Bryant, 1987).

As can be seen from Tab.1, composite resins are much less hard than enamel, and microfilled composite resins are much less hard than dentine. However, it would be a fallacy to attempt to predict the rate of wear according to the hardness of the composite resin. Wear is a complex process, apparently involving both mechanical and chemical interactions (of the composite resin restoration) with the oral environment (Draughn and Harrison, 1978). The process differs for different kinds of composites (Leinfelder, 1987), may not be identical in different individuals, and may change with changes in life style.

A number of laboratory studies have been carried out with differing results (Dickson, 1979), and often conflicting with the clinical experience (Cook, Beech and Tyas, 1984).

During the process of mastication, the organic matrix of macrofilled composite resins is abraded and reduced, the hard particles at first protrude above the surface, then, as they lose support, they are plucked out and the whole cycle is repeated. The matrix is reduced through scratches (Jorgensen, 1980), and through small cracks and fractures, which are the result of energy transmitted through the particles into the surrounding matrix (Leinfelder, 1987).

Porosity also plays a role, by concentrating stresses along the rims of the exposed voids, and also through the inhibition of

polymerisation by entrapped air (Leinfelder, 1985).

Wear produces a rough surface in macrofilled composite resins.

Microfilled composite resins, on the other hand, are abraded more uniformly, with the matrix and particles lost concomitantly (Asmussen, 1985).

While conventional composite resins tend to undergo a general loss of material - as if submerging in the preparation, described also as gradual bowling out followed by the systematic formation of a deep depression (Kusy and Leinfelder, 1977) - microfilled composite resins are prone to localised wear in the occlusal contact areas (Lutz, Phillips, Roulet and Setcos, 1984).

The low elastic modulus of microfilled composite resins (Bryant and Mahler, 1986) appears to be involved too, as it would eventually lead to failure due to the fatigue of the matrix (Leinfelder, 1987).

However, microfilled composite resins also undergo a certain amount of general loss of material. It is thus obvious that something else in addition to the masticatory forces is responsible for wear.

Söderholm, Zigan, Ragan, Fischlschweiger and Bergman (1984) found that when stored in water composite resins leach silicon and that this leaching did not decrease with time, indicating that the filler was attacked not only on the surface, but throughout the body, of the composite resin.

It has also been found that food simulating liquids (basically water solutions of alcohol) and organic acids of the plaque (acetic and propionic) reduce the hardness of BIS-GMA polymer, leading to surface staining and reduced resistance to wear. Alcohol and the plaque acids seemed to have less effect on those

composite resins containing a higher percentage of TEGDMA (a diluting monomer). (Wu and McKinney, 1982; Asmussen, 1984, McKinney and Wu, 1985; Asmussen and Hansen, 1986).

A considerable amount of work went into studying wear and combating it. Improvements have been achieved. While the first composite resins exhibited wear rates of over 100 micrometres a year, new posterior composite resins exhibit wear basically similar to that of amalgam. Robinson, Rowe and Maberley, (1988) found wear of a posterior (hybrid) composite resin (9) to be 70±36 micrometres after 36 months, which is comparable to the value they obtained for a conventional amalgam (10) at 67±36 micrometres, and Leinfelder (1988) quotes Mazer (a personal communication) as having shown the wear rate for both a microfilled composite resin (11) and a hybrid composite resin (12) to be less than 12 micrometres during a year.

PRODUCTS:

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

(2) Brilliant Lux. Coltene, Altstätten, Switzerland.

(3) Adaptic II. Johnson & Johnson Ltd.

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

(5) Silux. 3M, St. Paul, Minn., USA.

(6) Concept. Southern Dental Industries, Melbourne, Australia.

(7) Heliosit. Vivadent, Schaan, Liechtentein.

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

(9) Occlusin. ICI Dental, Macclesfield, England.

(10) Aristaloy. Engelhard Industries Ltd.,Baker Platinum Div., London, England.

(11) Heliomolar. Vivadent USA Inc.

(12) P-50. 3M Co.

	DENTINE	ENAMEL	CONVENTIONAL COMPOSITES	MICROFILLED COMPOSITES
POLYMERISATION SHRINKAGE vol. %	NA	NA	1.4 (1) 1.67-5.68 (2)	1.7 (1)
LIN. COEFFICIENT OF THERMAL EXPANSION ($mm/mm.^{o}C$) $x10^{-6}$	10.59 (3)	16.96 (3)	35.34 (4)	60.42 (4)
THERMAL CONDUCTIVITY $cal/sec/cm^{2}/(^{o}C/cm)$ $x10^{-4}$	15 (5)	22 (5)	25-30 (6)	12-15 (6)
THERMAL DIFFUSIVITY (mm^{2}/sec) $x10^{-2}$	18.3 (5)	46.9 (5)	21.1-67 (7)	15.5-22 (7)
RADIOPACITY mm of Aluminium	0.79 (8)	2.22 (8)	>0-2.52 (hybrids) (8)	>0-1.93 (8)
WATER SORPTION mg/cm^{2} (1 week)	NA	NA	0.6 (1)	1.4 (1)
COMPRESSIVE STRENGTH MPa	208.3-306.9 (9)	95.1-290.3 (9)	235 (1)	276 (1)
TENSILE STRENGTH MPa	52.1 (10)	10.4 (10)	48.61 (11)	44.44 (11)
MODULUS OF ELASTICITY GPa	16.66-18.75 (12)	63.19-96.53 (13)	9.7-16.9 (14)	4.5-7.9 (14)
HARDNESS KNOOP	68 (15)	343 (15)	55 (16)	25 (16)

TAB.1. PHYSICAL AND MECHANICAL PROPERTIES OF COMPOSITE RESINS.

(1) Phillips, 1982, p. 219.
(2) Goldman, 1983.
(3) Hengchang, Wenyi and Tong, 1989.
(4) Phillips, 1982, p. 220.
(5) Craig, 1989, p. 52.
(6) Craig, 1989, p. 262.
(7) Watts, Haywood and Smith, 1983.
(8) Stanford, Fan, Schoenfeld, Knoeppel and Stanford, 1987.
(9) Stanford, Weigel, Paffenbarger and Sweeney, 1960.
(10) Bowen and Rodriguez, 1962.
(11) Marzouk, Simonton and Gross, 1985, p. 173.
(12) Craig and Peyton, 1958.
(13) Craig, Peyton and Johnson, 1961.
(14) Bryant and Mahler, 1986.
(15) Craig, 1989, p. 100.
(16) Phillips, 1982, p. 221.

NA: Not Applicable

1.5.2 Biological considerations.

Teeth filled with unlined silicate cement usually suffered pulpal damage. This was attributed to the toxicity of the material - at first to its content of arsenic and, when arsenic was regulated, to its prolonged acidity (1.2). Later, with direct filling resins, the pulpal damage continued. It was attributed once again to the toxicity of the material (ibid.).

This history of aesthetic restorative materials may have conditioned us towards composite resins. Phillips (1982, p. 229) stated, "The irritational characteristics of composite resins are comparable to those of the unfilled acrylic resin."

Langeland (1970) concluded that pulp protection was a necessity with composite resins and found the film forming liner inadequate.

Goto and Jordan (1972) found a direct correlation between the remaining dentine thickness and the severity of the histological response of the pulp.

Stanley, Going and Chauncey (1975) stated "The newer composites, although free of methacrylic acid and of a neutral pH, were still found to be toxic to the pulp." Their study examined the effect of composite resins (1, 2) on the pulps of teeth which were later extracted for orthodontic reasons. They found the damage to the pulp was greater if the dentine was pretreated with acid (phosphoric or citric). They attributed this to the toxicity of the material and increased permeability of the dentine after acid pretreatment.

However, what was the toxic component?

Stanley, Bowen and Folio (1979) studied the pulpal response to

eight components of composite resins (BIS-GMA, diluent monomer, filler, initiator, activator, UV photoinitiator and UV stabiliser) which they placed in 100% form on the pulpal walls of cavities cut into teeth of primates. The materials were sealed in the teeth with zinc oxide-eugenol cement. The responses were graded from 0 (no inflammation) to 4 (abscess or necrosis). They found that none of the materials could be considered significantly irritating, and that the average response level for each of the materials was less than 0.5 on their scale. However, this does not mean, as they pointed out, that interactions among these components are also harmless.

An interesting experiment, carried out by Cox, Keall, Keall, Ostro and Bergenholtz (1987), investigated the biocompatibility of several dental materials - amalgam, zinc phosphate cement, composite resin (3) and silicate cement. These materials were placed against exposed pulps in cavities cut into the teeth of monkeys. Half of the teeth in each group were filled completely with the studied material, in the remaining half of the teeth the outer part of the material was removed and replaced with zinc oxide-eugenol cement. Two distinct types of reaction were found: either the pulps displayed severe inflammation or necrosis, or the pulp tissues were healing with hard tissue repair. The first kind of reaction was associated with the cavities not sealed with zinc oxide-eugenol cement, the second kind with the sealed ones. The researchers also found that stainable bacteria were seldom found under the sealed restorations.

This aspect of the problem had been investigated previously. Brännström and Nyborg (1973), as part of a wider experiment, treated the cavities of human teeth with a microbicidal fluoride

solution (4). The cavities were then restored with a composite resin (5). In one group, the composite resin was left intact. In another group, the outer part of the composite resin was replaced with zinc oxide-eugenol or Cavit. The teeth were extracted after three to six weeks and examined. In the former group, all cavities but one contained bacteria. In the latter group, none of the cavities contained them.

In 1984 (a) Brännström stated: "In total, we have examined hundreds of teeth with deep cavities...we have used various composite resins...The results have pointed to the same conclusion, namely: when infection is avoided there is no appreciable irritation to the pulp..."

Experiments with ferrets (Browne, Tobias, Plant and Crombie, 1981), and germ-free rats (Watts, 1979; Watts and Paterson, 1981) confirm the importance of the bacterial presence on pulpal response.

The above would seem to indicate that bacterial invasion, rather than toxicity of the material, is the main cause of pulpal problems associated with composite resin restorations. However, while Watts (1979) investigating the response of the exposed pulp to silicate and zinc phosphate cements reported absence of inflammation of the pulp in germ free animals, he also reported the presence of pulpal necrosis in these animals. In the past the importance of bacterial contamination may have been underestimated. To consider it the only source of problems would be going to the other extreme.

As pointed out earlier, while the components of composite resins may be harmless, their interactions may not be. Harsanyi, Angelopoulos and Gourley (1974) studied the biologic effects of

composite resins (5, 6, 7) by implanting samples of composite resins prior to setting into subcutaneous tissue of mongrel dogs. While the composite resins were markedly less irritating than zinc oxide-eugenol, they were more injurious to the tissue than control wounds without any implanted material. It is possible that reactive radicals generated during the polymerisation may be injurious to the pulp (Kafrawy, 1983). Harsanyi, Angelopulos and Gourlay (1974) also found differences among the composite resins, with Epoxylite HL-72 (7) being the most inert of the materials tested.

In this context it is also interesting to note that formaldehyde was found to be formed in VL, UVL and chemically-activated composites (Oysaed, Ruyter and Sjovik Klemen, 1988). Formaldehyde is responsible for more than one third of all allergic reactions, and Lind (1988) suspected it to be the causative factor of oral lichenoid reactions found in 17 patients. An alternative explanation was that the lichenoid reaction was caused by plaque accumulated on the surface of the composites.

Tertiary amines (activators) are well-known potential allergens (Dahl, 1982, p. 181). BIS-GMA itself is a sensitiser and was found to be the cause of the dermatitis of a dental assistant (Kanerva, Jolanki and Estlander, 1986). Dental composite material has also been found to cause extraoral sensitivity - itching and measleslike rash on chest, arms and legs of a patient (Nathanson and Lockhart, 1979). Other components such as BIS-MA, BIS-EMA, TEGDMA, methyl-methacrylate monomer, peroxides and also impurities may have allergenic potential (Dahl, 1982, p. 180; Kanerva, Jolanki and Estlander, 1986).

A search through the Australian MEDLINE network of MEDLARS

system back to 1977 failed to match "composite resins" with "malignancy", thus indicating that this data base of over 3,000 medical and dental journals has no reports on malignancy attributed to composite resins. However, it should be born in mind that while perhaps the status of oral lichen planus as a premalignant condition is not uncontroversial (Krutchkoff, Cutler and Laskowski, 1978), there have been reports of its malignant transformation (Lind, Koppang and Aas, 1985). Formaldehyde itself is a carcinogen, although again not without controversy (Perera and Petito, 1982).

PRODUCTS:

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

(2) HL-72. Lee Pharmaceuticals, South El Monte, Calif., USA.

(3) Command Ultrafine Type II. Kerr/Sybron Co., Romulus, Mich., USA.

(4) Tubulitec. Dental Therapeutics AB, Nacka 1, Sweden.

Buffalo Dental Mfg. Co., Brooklyn, NY, USA.

(5) Adaptic. Johnson & Johnson, New Brunswick, NJ, USA.

(6) Concise. Minnesota Mining & Manufacturing Co., St. Paul, Minn., USA.

(7) Epoxylite HL-72. The Epoxylite Corp., Dental Division, South El Monte, Calif., USA.

1.5.3 Aesthetic considerations.

Of the elements contributing to the appearance of a crown (2.4.1.4) only the colour (and translucency) and the gloss of composite resins are pertinent here. Other elements will be discussed in the following chapter.

Colour is a phenomenon consisting of three dimensions:

Hue - or colour in the narrow sense. This is determined by the wavelength and can be described as red, yellow, etc.

Value - or brightness. This is the dimension perceived by the colourblind, or on the black and white photographs and can be described as darker or lighter.

Chroma - or saturation. This is determined by the amount of the particular hue and can be described as strong or weak (Sproull, 1973a; Preston and Bergen, 1980, p.4-6; Phillips, 1982, p. 50).

These three dimensions were organised by A. H. Munsell (Preston and Bergen, 1980 p. 7) into a system which can be visualised as a series of wheels stacked one upon another, forming an irregular cylinder. The hues are arranged around the rim of the wheels. The wheels from the lowest to the highest are of increasing value. The chroma is measured along the spokes from the colourless axis to the strongest saturation at the rim. Importantly, any colour can be accurately placed within this system by a set of coordinates, in the following order: hue, value and chroma.

Hue is expressed by a numeral (indicating the subdivision) and by a letter (indicating the hue, e.g. Y for yellow, YR for yellow red, etc). Value and chroma are expressed by numerals (indicating the brightness and saturation respectively), separated by a stroke.

Thus 9YR 2/9 would indicate yellow red colour verging on yellow, rather dark and strong (highly saturated).

Through spectrophotometric studies Sproull (1973b) found natural teeth to be within the range 7.5YR to 2.5 Y for hue, 5.8/ to 8.5/ for value and /1.5 to /5.6 for chroma.

Using these values Dennison, Powers and Koran (1978) found through visual comparison that most of the composite resins tested outside the natural tooth range. Cook and McAree (1985), however, comparing spectrophotometrically 1mm thick samples of composite resins with 1mm thick sections of human enamel and dentine, found that they generally exhibited a similar range. It is worth noting that the composite resins tested by Dennison, Powers and Koran were mostly chemically-cured conventional composite resins, while Cook and McAree tested light-cured microfilled composite resins.

Most composite resins come in several shades, of which the universal is somewhat more translucent, thus allowing the restoration to "pick up" the colour of the patient's own teeth. The manufacturers achieve other shades by the addition of pigments - these are small amounts of coloured inorganic compounds (Craig, 1981).

The colour of composite resin restorations may be further modified by opaquers and tints. They are BIS-GMA, or urethane based dimethacrylates containing various dyes or pigments. Although they are usually interchangeable (Feigenbaum and Mopper, 1988, p. 145), it is sensible to use the opaquers and tints compatible with the matrix of the composite resin (2.4.8.6).

The manufacturers supply shade guides, which are generally unsatisfactory. According to Sproull (1973b) they do not extend

through the volume of colour-space required, and they are not orderly or systematically arranged. To this it should be added that they are not fabricated of composite resins, but usually of unfilled resins (Feigenbaum and Mopper, 1988, p. 147). Although recently there have been improvements in shade guides, it is prudent to use them only for preliminary selection.

An additional colour problem is metamerism - a composite resin restoration may appear well colour-matched under one light source, but the match is poor under different illumination. This is due to the fact that the colour may not always be caused by a single wave length, but also by a dominant wavelength resulting from interaction of several wave bands (Preston and Bergen, 1980, p. 16). The result of this interaction depends on the amount of light energy the light source emits in the particular wave bands and, as this may change from one light source to another, the resulting dominant wavelength will also change. With different materials (composite resin versus dental tissues) this problem cannot be completely eliminated, and it is a good policy to do colour-matching under two different light sources (Shillingburg, Hobo and Whitsett, 1981, p. 436-7; Phillips, 1982, p. 52).

Composite resins are subject to discoloration. This can be either external or internal. The external staining may be due to a rough surface and plaque collection. In addition, the propionic and acetic acids present in plaque (Asmussen, 1984; Asmussen and Hansen, 1986) and some chemical compounds, such as alcohol (Wu and McKinnon, 1982; McKinnon and Wu, 1985), reduce the hardness of the BIS GMA polymer. A softened surface is more prone to staining (Asmussen and Hansen 1986). The more TEGDMA (and the less BIS-GMA)) in the matrix,

the greater the resistance of the composite resin to the surface softening and staining (Asmussen, 1985; Asmussen and Hansen 1986). Microfilled composite resins fare well, as far as the external discoloration is concerned, because of their better and more permanent polishability and their lower content of BIS-GMA (Lutz and Philips, 1983; Asmussen, 1985; Jordan and Gwinnett, 1988, p. 8-17).

One form of external discoloration is marginal discoloration. However, rather than being a property of composite resins, it is an indication of an overhang, leakage or a caries.

Internal discoloration has been ascribed to the presence of tertiary amines, which are the activators in chemically-cured composite resins. Some brands of the light-cured composite resins may also contain amines, to enhance the effect of the light sensitive catalyst (Asmussen, 1985). This discoloration, which is characterised by yellowing and darkening, may be ultraviolet light induced (Ferracane, Moser and Greener, 1985). Colour changes may also be induced by heat, or a xenon light, which has a spectral wave-length distribution closely resembling the natural light (Brauer, 1988).

Asmussen (1985) stated that the internal discoloration is decreased with an increased amount of BIS-GMA, which does not favour the microfilled composite resins. However, it appears BIS-GMA monomer itself will cure and turn yellow under intense UV illumination (Ferracane, Moser and Greener, 1985).

The light-cured composite resins are more colour stable than the chemically-cured ones, and within the same brand the darker shades appear less susceptible to colour changes (Brauer, 1988).

The opacity of composite resins increases with time (Loeys,

Lambrechts, Vanherle and Davidson, 1982). This is thought to be caused by microcrack formation due to hydrolytic degradation (Söderholm, Zigan, Ragan, Fischlschweiger and Bergman, 1984), and it occurs at a lower speed with microfilled composite resins than with conventional ones (Loeys, Lambrechts, Vanherle and Davidson, 1982).

The gloss of composite resin restorations depends primarily on the size of the filler particles and, in degree and permanency, it increases in the following order: conventional composite resins, hybrid composite resins, microfilled composite resins (Phillips, 1982, p. 234-5; Lutz and Phillips, 1983; Marzouk, Simonton and Gross, 1985, p. 170-2; Jordan and Gwinnett, 1988, p. 8-17; Badenhorst and deWet, 1987).

1.6 CLASSIFICATION OF COMPOSITE RESINS

As pointed out earlier (1.2), it is essential for a practitioner to know what can be expected of different types of composite resins, or, viewed alternatively, which type of composite resin has the properties most suitable for any particular case.

1.6.1 Classification according to Lutz and Phillips.

A classification by Lutz and Phillips (1983) based on the type of the filler divides composite resins into groups which have certain common properties. Marzouk, Simonton and Gross (1985, p. 171-2) divided composite resins into 6 generations in chronological order. However, these generations were specified according to their dispersed phase.

The Lutz and Phillips classification will now be given. For each group the corresponding Marzouk, Simonton and Gross's generation will be mentioned, in addition to a number of group characteristics.

1.6.1.1 Traditional composite resins. These are also called conventional or macrofilled composite resins. This system corresponds to the first generation of the Marzouk, Simonton and Gross classification. Bowen (1963) used particles of up to 150 micrometres in size. The commercial traditional composite resins used to have particles 5 to 30 micrometres in size, splinter shaped. More recently the particles tend to be rounded and 1 to 5

micrometres large. Even so, the particles are larger than the wavelength of the visible light, which makes these composite resins difficult to polish. They are prone to plaque collection, with implications not only for the restoration itself, but also for the periodontal tissues. However, although they are prone to surface staining, their internal colour stability is good. The particles are subject to plucking, which results in a high rate of wear. However, as their filler loading may reach 80% or more by weight, these composites tend to be dimensionally stable, mechanically strong, their modulus of elasticity may be comparable to that of dentine and their water sorption is relatively low.

1.6.1.2 Hybrid composite resins. Apart from macrofiller particles (the same as traditional composite resins), the organic matrix is reinforced also with microfiller particles. These are either colloidal silica 0.04 micrometres in size, or pyrogenic silica 0.05 to 0.1 micrometres in size. The macrofiller and the microfiller particles usually exist in a ratio of 75:25, and the total inorganic filler loading may reach 80% or more by weight. This system corresponds to the third generation of the Marzouk, Simonton and Gross classification. The properties of these composite resins fall in between those of macrofilled and microfilled composite resins.

1.6.1.3 Homogeneous microfilled composite resins. These correspond to the second generation of the Marzouk, Simonton and Gross classification. The microfiller particles are directly admixed into the organic matrix. They are highly polishable, and their gloss

tends to be permanent. They should resist well the plucking-out mechanism of wear. However, their loading tends to be low as it quickly increases the viscosity. (The loading of microfilled resins generally does not exceed 55 to 65%, and may be as low as 36 to 37% by weight.) Consequently, their mechanical and physical properties tend to be inferior to those of the traditional composite resins.

1.6.1.4 Heterogeneous microfilled composite resins. These were developed by the manufacturers in an attempt to increase the loading with as little increase in the viscosity as possible. This system is divided into three subclasses:

Heterogeneous microfilled composite resins with splintered prepolymerised particles. This subclass corresponds to the fourth generation of the Marzouk, Simonton and Gross classification. The splintered prepolymerised particles (sometimes incorrectly called "organic particles") are fabricated by heat curing of resin matrix loaded with pyrogenic silica. The resulting solid body is milled into particles from 1 to 200 micrometres in size. These are then admixed into a microfiller-reinforced continuous phase. Their properties are similar to those of the homogeneous microfilled composite resins but they tend to be less viscous. However, they exhibit the highest shrinkage of all composite resins (Marzouk, Simonton and Gross, 1985, p. 171-2). They are also technique sensitive - the bond between the prepolymerised particles and the organic matrix is polymeric and may fail. Finishing techniqes using green and white stones, or tungsten carbide burs, may fracture the prepolymerised particles and form fissures along the interfacial

surface. This may be avoided by using polishing disks or superfine diamonds. The composite resins of this subclass may not be strong enough in stress-bearing situations.

Heterogeneous microfilled composite resins with spherical prepolymerised particles. This subclass corresponds to the fifth generation of the Marzouk, Simonton and Gross classification. Pyrogenic silica is here incorporated into partially cured polymer spheres 20 to 30 micrometres in size, and these spherical prepolymerised particles are then admixed into a microfiller reinforced continuous phase. The spherical shape of the prepolymerised particles improves their wettability, and consequently their bonding, to the continuous phase. Mathematically calculated size distribution of the spheres allows for a dense loading. The composite resins of this subclass tend to be stronger and their polymerisation shrinkage is reduced compared with the composite resins of the previous subclass. In other respects their properties are similar.

Heterogeneous microfilled composite resins with agglomerated microfiller complexes. This subclass corresponds to the sixth generation of the Marzouk, Simonton and Gross classification. The microfiller complexes are 1 to 25 micrometres in size and are purely inorganic, as they consist of sintered microfiller particles. These complexes are admixed into a microfiller-reinforced continuous phase. A high loading can be achieved, which provides for good physical and mechanical properties, while retaining the surface properties. The composite resins of this subclass are also

somewhat condensable.

(Lutz and Phillips, 1983; Marzouk, Simonton and Gross, 1985, p. 171-2; Jordan and Gwinnett, 1988, p. 8-17; Leinfelder, 1987; Badenhorst and deWet, 1987; Wilson, 1988).

1.6.2 Classification according to Badenhorst and deWet.

The Lutz and Phillips classification was further developed by Badenhorst and deWet (1987), according to the size of the filler particles within the systems:

Group 1. Conventional or macrofilled composites.

1.1 Composite resins with large macro filler particles (5 to 50 micrometres).

1.2 Composite resins with medium macro filler particles (3 to 10 micrometres).

1.3 Composite resins with small macro filler particles (1 to 3 micrometres).

Group 2. Microfilled resins.

(Badenhorst and deWet prefer to call the materials of this group "resins" as some of their physical properties do not satisfy the minimum ADA requirements for composite resins.)

2.1 Homogeneous microfilled resins.

2.2 Heterogeneous microfilled resins.

Group 3. Hybrid (Blended) composites.

These composite resins, apart from microfiller particles, contain also macro filler particles.

3.1 Hybrid composites with large macro filler particles (5 to 50 micrometres).

3.2 Hybrid composites with medium macro filler particles (3 to 10 micrometres).

3.3 Hybrid composites with small macro filler particles (1 to 3 micrometres).

This classification is a useful and logical development of the Lutz and Phillips classification, since the size of the macrofiller particles, as pointed out earlier (1.3.1), has a considerable influence on some properties of the composite resins.

However, "today the term 'hybrid composite' usually refers to materials that contain ground fillers having an average particle size of 0.6 to 1.0 micrometre in combination with 10 to 15 wt.% microfiller" (Phillips, 1991, p.221). They have radiopacities greater than enamel, and because of their strength and smooth surface they can be used for Class IV cavities (ibid., p. 229).

CHAPTER 2

DIRECT COMPOSITE RESIN CROWNS

2.1 DEFINITIONS

2.1.1. Crown.

The word "crown" according to the Macquarie Dictionary (1981, p. 449) has 31 meanings. The one relevant for this treatise is 16.b.:

(Crown is) "an artificial substitute, as of gold or porcelain, for the crown of a tooth".

The definition found in Butterworths Medical Dictionary (1978, p. 435) says that a crown is "A restoration used in conservative dentistry which is fixed on the root of the tooth to replace a natural crown which has been lost by caries or fracture or which is unsightly; an artificial crown."

However, these definitions are not adequate as they seem to talk about the substitution for, or replacement of, the whole "natural crown".

The definition which seems the least objectionable is from Malone, Mazur, Sawyer, Tylman, Henneman and Jameson (1978, p. 128), which says that an artificial crown is "Fixed restoration of the major part or of the entire coronal part of a natural tooth,

restoring its anatomy, function and esthetics; usually of metal, porcelain, synthetic resin or their combination."

Yet, even this definition is not quite satisfactory. It can be argued that a large MOD inlay is a restoration "of the major part...of the...coronal part of a natural tooth", but it is not a crown. In addition, it is not clear what is meant by "coronal part of a natural tooth". It would be more precise to refer to the "clinical crown", which is the "Portion of a natural tooth that extends from the bottom of the sulcus (epithelial attachment) to the occlusal surface or incisal edge." (Malone, Morgano, Young and Schmidt, 1989, p.149).

However, what chiefly seems to be lacking in the above mentioned definitions is the specification that a crown is a restoration restoring a substantial part of the surface of the natural crown. It would appear that at least about a half of the surface needs to be restored (Morgano, Garvin, Muzynski and Malone, 1989, p.1).

However, the name of a restoration is also a matter of tradition. Porcelain, or composite resin restorations restoring about a half of the surface of the clinical crown of an anterior tooth, are usually referred to as veneers (Clinical eesearch associates, 1985; Larson and Phair, 1987; Bertolotti, 1988).

2.1.2 Direct composite resin crown.

A "direct composite resin crown" is a crown fabricated of a composite resin, although in some cases it may contain metal components such as a post-core, a post or a pin.

It is fabricated directly, that is in the mouth of the patient, usually in one visit.

A direct composite resin crown is retained by bonding (to the enamel, dentine, base, restorations present in situ), by mechanical retention onto its metal components (which are either cemented or retained mechanically) or onto the tooth, or by a combination of the above.

In order to distinguish it from composite resin veneers, in this treatise the term "direct composite resin crown" will refer to composite resin restorations restoring the whole of the surface of a clinical crown, except that it is recommended that such a crown should be kept 0.5 to 1 mm short of the gingival margin (2.4.3.2).

The amount of the coronal tissues replaced by the direct composite resin crown may vary from the total replacement in cases "where little (supragingival) tooth structure remains" (Carter, 1983), to the replacement of only part of the enamel in cases of amelogenesis imperfecta in young patients (Lamb, 1974; Alexander, 1984).

2.2 HISTORY

2.2.1 History of crowns.

Dentistry is an ancient field of human endeavour. In Ancient Egypt, those who treated teeth were hieroglyphically represented by an eye and horizontal elephant tusk (Hoffmann-Axthelm, 1981, p. 21). From the days of the 5th dynasty of the Old Egyptian Kingdom (2686-2160 BC) the name of "one who deals with teeth" has been preserved: Nfr-irjts (ibid.).

During the Middle Egyptian Kingdom (2040-1785 BC) the beginnings of scientific systemisation evolved (ibid., p. 19). Further progress was made during the "illustrious New Kingdom" (1552-1070 BC) (ibid.). The Ebers Papyrus from 1550 BC often referred to "bennut blisters in the teeth" and gave remedies to cure the growth of "uxedu" - painful swelling, perhaps periapical abscess (Guerini, 1909, p. 19-23). Unfortunately, the document said nothing about dental restorations or about the replacement of missing teeth, and according to Bremner (1954, p. 40) "archaeology has not produced one shred of evidence of mechanical dentistry in Ancient Egypt."

This statement is no longer exactly correct. However, the teeth wired together found in Egyptian mastabas are difficult to interpret (Hoffmann-Axthelm, 1979; Blustein 1987). It is possible, indeed probable, that the work was done post-mortem.

The oldest accepted examples of prosthodontic work are Etruscan and come from the sixth century BC (Tylman and Tylman, 1960, p. 23). They, as well as similar but inferior Phoenician specimens, are

fixed replacements of missing teeth, and in some ways resemble our Maryland bridges, although their retainers completely encircled the abutments. The pontics were usually carved from a tooth of an ox, although at times human teeth were utilised; the retainers consisted of soldered gold rings, or of gold wires.

The recent discovery of a bronze wire implanted in the root canal of an upper right lateral incisor in a skull found in the Negev Desert was more likely the discovery of a plug intended to prevent "'toothworms' from burrowing into the tooth" than the discovery of a remnant of a postcrown (Zias and Numeroff, 1987).

The Romans were the first to fabricate a true crown - the lower incisor crown excavated at Satricum and dating from about 100 AD (Bremner, 1954, p. 55; Guerini, 1967, p. 101) consisted of labial and lingual swaged gold plates soldered together and was part of a splint-like structure. Perchance it was fabricated by Cascellius, who according to the Roman writer Marcus Valerius Martialis did dental work (Martialis, 1968, p. 196) and who, with the exception of the old Nfr-irjts, may be the first dentist known to us by name. According to Bremner (1954, p. 55), Martialis described Cascellius as "grown rich like a senator". Bremner, unfortunately, did not give here a specific reference, and the story, like so many regarding purported dentists' wealth, may be apocryphal.

The above mentioned Roman crown, however, may represent the ancient peak. The Empire continued for another 400 years, but we have no evidence of further progress and it took some fifteen centuries for crowns to reappear.

The affair of the Silesian boy, who was supposed to have grown a gold tooth in 1593, suggests two things:

a. That the artisans of the day were sufficiently skilful to fabricate a metal crown.

b. That this crown was either unique, or one of so few that some very clever and respected people were fooled by it.

The "gold tooth" (which was the lower left first molar) itself lasted three years, during which time it was exhibited at yearly fairs. Then the fraud became obvious, as the crown became perforated (Weinberger, 1948, p. 273-5; Guerini, 1967, p. 214-7; Hoffmann-Axthelm, 1981, p. 163) .

However, a continuously strengthening economic base and expanding scientific knowledge led to real progress in this area. Between 1530 and 1728 about four hundred and fifty dental treatises were written (Weinberger, 1948, p. 257). The first cast gold crowns were fabricated in France in the first half of the 18th century. When they were on anterior teeth, they were enamelled (Tylman and Tylman, 1960, p. 24). Pierre Fauchard (1678-1761), called the father of modern dentistry, fabricated post crowns (root canals were filled with lead) (Bremner, 1954, p. 102).

In 1889, C. Land of Detroit developed a method of constructing the full porcelain veneer crown (Tylman and Tylman, 1960, p. 26). From the mid 1950's, metal bonded ceramics started to be available on the dental market (Johnston, 1960). In the 1980's, castable ceramics appeared, based on the work begun in the late 1970's (Sumii, 1980).

The development of composite resin restorative materials based on the work of R.L. Bowen began in the late 1950's (Bowen, 1958). Together with the development of adhesive dentistry, begun with the work of M.G. Buonocore in the mid 1950's (Buonocore, 1955), this

allowed the development of direct composite resin crowns to be described in this treatise.

Development has not ceased, but is, on the contrary, accelerating. Better understanding of physical, chemical and biological processes leads to new ways of preparation and fabrication, using new materials to produce restorations which are more mechanically, biologically and aesthetically acceptable.

2.2.2 History of composite resin crowns.

It seems most probable that the first composite resin crowns were fabricated in the 1960's. However, the earliest reference in dental literature that this author has been able to locate is a description by Mosier (1971) of emergency treatment of "...fractured teeth through the use of a two-component resin". A macrofilled composite resin (1) was placed with a plastic instrument over the fractured tooth. It is perhaps indicative of the early days that although Mosier called this restoration "temporary crowns", he preferred it not to have the shape of the tooth to reduce the danger "of the tooth becoming loosened". One of the advantages of the material was thought to be that "it does not adhere after hardening" (so that it could be removed for finishing, after which it was cemented with zinc phosphate cement). Mosier stated, "Crowns of this type have been inserted which lasted for several months".

In January 1972, Staffanou described a method of restoring fractured incisal angles, using a restorative unfilled resin, or "one of the new composite resin materials". The retention was provided by an undercut preparation at the site of the fracture. However, Staffanou also said, "Etching procedures also may be useful with this technique". The material was placed using a celluloid crown form or a stainless steel matrix band.

As the techniques developed, composite resin crowns became more widely used, their indications being fractured anterior teeth (Bizga, 1974), treatment of amelogenesis imperfecta (Lamb, 1974), treatment of medically compromised patients (haemophiliac) (Kushner, 1974), treatment of ankylosed primary molars (Bonin,

1976), conservative (and economic) treatment of grossly carious anteriors (Fuller and Denehy, 1976) and restoration of primary anterior teeth (Weiss, 1979).

In 1978, Ulvestad published results of a five year evaluation of 253 composite resin crowns. The patients were children 10-14 years old. The description of the method of fabrication is not very detailed, but it appears that no prophylaxis was carried out, 1-2 mm bevel was placed, and all exposed dentine was lined with calcium hydroxide. The length of etching with unbuffered 50% orthophosphoric acid is not indicated. No intermediate resin (bonding agent) layer was used. The macrofilled composite resins (1,2,3) were all placed with the aid of a celluloid crown form. The restoration was "formed and trimmed" with a diamond point. Only one retentive failure at the enamel-resin interface occurred, although there have been 31 fractures of the composite resin material, mostly caused "by new trauma". The greatest problems were surface discoloration (250 crowns), body discoloration (211 crowns) and abrasion (184 crowns).

A somewhat similar result was reported by Low and Majid (1979). Their patients ranged in age from 8 years 10 months to 24 years 7 months. Prophylaxis using pumice and water was carried out. A half enamel preparation 1.5 to 2.0 mm wide was prepared with a scalloped margin on the labial surface. The tooth was etched for 60 seconds with a bufferd 50% phosphoric acid conditioner. No intermediate bonding agent was used, and the macrofilled composite (3) was placed with a celluloid crown form. The finishing was done with diamond burs and wheels, and the polishing with white stones and a polishing paste. Of 30 restorations with the observation period of

12 to 18 months, only one was lost. However, of the remaining 29 restorations 23 were discoloured.

However, by the time these studies were published, they were already dealing with obsolete materials and methods, as in the meantime UVL-activated materials and also VL-activated microfilled resins appeared on the market.

In 1972, Ward, Buonocore and Woolridge described fabrication of a "sleeve-fit partial crown", which utilised UVL-activated bonding agent Nuva-Seal (4) and chemically-cured macrofilled composite resin Adaptic (1). They placed Dycal (5) "over all exposed dentin, and overlapping the dentino-enamel junction", neither pumiced nor prepared the enamel, etched with buffered 50% phosphoric acid for 60 seconds and placed the composite resin with a celluloid crown form. "High polish finish" was obtained by applying a thin coat of Nuva-Seal (4). They reported that of thirty one such crowns which have been in service for between thirteen and sixteen months only one was lost (due to an automobile accident).

Roberts and Moffa (1973) reported on sixty anterior teeth restored with UVL-activated bonding agent (4) and chemically-cured macrofilled composite resins Blendant (6), Epoxylite HL-72 (7), Concise (3) and Adaptic (1). "All materials were retained for two years with no instance of retention failure." They did not mention pumicing the teeth, placed a 45 degree bevel on the fractured enamel, etched with buffered 50% phosphoric acid conditioner for 60 seconds and used celluloid crown forms to place the composite resins, but it is not clear how far on the crowns of the teeth these restorations extended. Finishing and polishing was done with diamond points, finishing strips and impregnated rubber wheels.

In 1974, Oppenheim and Ward reported on 115 fractured anterior teeth restored with UVL-activated bonding agent Nuva-Seal (4) and chemically-cured macrofilled composite resin Adaptic (1). They did pumice the teeth prior to etching, but mechanical preparation was used only when the fracture site was carious. Exposed dentine was always protected with Dycal (5). The length of etching with 50% phosphoric acid was not indicated. The composite resin was placed with "a suitable matrix". Finishing was done with a "fine diamond or 12 fluted bur". Their success rate (intact restorations) was 80% (observation time was 9 to 21 months). Of 23 restorations lost, 11 were lost in the first month. The failures were attributed to faulty techniques (overfinishing and moisture contamination), biting hard objects, occlusal disharmonies and traumas. They reported only slight staining and wear was present in only "several instances".

In 1973, Buonocore and Davila described restoration of fractured anterior teeth using a UVL-activated bonding agent Nuva-Seal (4) and UVL-activated composite resin Nuva-Fil (8). They pumiced the teeth, but did not prepare them mechanically, and covered all exposed dentine and "about half the thickness of the exposed enamel" with Dycal (5). However, if "little or no dentin was exposed, the Dycal application was omitted". The enamel surfaces were "acid conditioned" for one minute. The restorative material was patted into place with a "Teflon, flat, bladed instrument", although in some instances a crown form with "an open labial front" was used. If the restoration was more than 2 mm thick, it was placed in increments. Finishing and polishing was done immediately with sandpaper disks, abrasive strips, fine diamonds, fine stones and a rubber wheel. They reported on 104 of these "sleeve-fit partial

crowns". During the observation period (8 to 24 months) "marginal integrity was maintained in all instances", there was "relatively little wear", the surfaces were "smooth with a satiny, semigloss finish". The restorations were lost in two instances.

Meurman and Helminen (1974) report on fifteen teeth restored using the same materials and method as Buonocore and Davilla (1973). After one year, all fifteen restorations were retained, two were stained due to heavy smoking, and all fifteen restorations lost their surface glaze.

Helle, Sirkkanen and Evälahti (1975) compared two groups of restorations done according to Buonocore and Davila (1973). In the first group, UVL-activated materials Nuva-Seal (9) and Nuva-Fil (10) were used, in the second group selfpolymerising (chemically-activated) composite resin and fissure sealant Concise Composite Enamel Bond (11). Both restorative materials were retained in all cases and there was no significant difference in discoloration (8.5% of Nuva and 6.8% of Concise crowns). The follow-up time for the first group (47 restorations) was 20-24 months, for the second group (44 restorations) 18-20 months.

Somewhat less favourable results were achieved by Watkins and Andlaw (1977). They reported on 121 restorations of Nuva-Seal (9) plus Nuva-Fil (10) observed for a 12 to 30 months' period. 17% of restorations were lost. Of the remaining restorations, 22% had poor colour and 34% had unsatisfactory cervical margins. It is interesting to note that these restorations were fabricated without mechanical preparation, the teeth were "polished with a commercial paste containing fluoride", "any exposed dentine" was covered with Dycal and the activated Nuva-Seal was used for up to one week

(rather than prepared fresh daily as recommended by the manufacturer). Nuva-Fil was applied in crown forms (which means its thickness may have exceeded that recommended by the manufacturer to allow adequate curing), and some of the defective margins were on teeth with subgingival fractures.

In 1983, Carter described construction of "an anterior microfine filled resin crown". The retention for this "intermediate or provisional" crown was provided by three or four threaded pins, if the tooth was vital, and by a post and two pins if the tooth was root filled. A cone of the microfilled resin was built and cured over these metal elements. Then microfilled resin was applied in a celluloid crown form and cured. The crown was "shaped and polished using fine diamonds and soft sandpaper disks". Carter suggested these crowns were indicated where "the cost of (porcelain to metal) bonded crowns cannot be justified, on teeth with doubtful prognosis, in the aged where life expectancy is limited, in indigent and institutional patients".

Alexander (1984) described the treatment of a patient with hypocalcified amelogenesis imperfecta. Anterior teeth were restored with composite resin crowns. As there was little enamel on these teeth, the retention was provided with mechanical undercuts and also with a dentine bonding agent (12). On a six month recall the restorations appeared intact and no marginal leakage could be detected clinically.

Exner (1984) described the construction of a "semi-permanent crown for fractured endodontically treated anterior". The retention was provided by a tapered parapost, on which a hybrid composite resin core was built. A microfilled resin was placed on this core

with a template.

Talbot (1985) described the treatment of an elderly patient, whose dentition suffered from severe attrition/erosion. Multiple composite resin crowns were placed in one visit with the help of a "clear custom matrix" made of soft clear rebase acrylic (13), which had been constructed on a "diagnostic wax-up". Talbot also stated that the same treatment had been used for patients with Bulimia nervosa or with a "history of oesophagal reflux".

In 1986, Jordan (p. 66-69, 80-81) described the fabrication of composite resin post crowns using paraposts (14) and the building up of peg-shaped maxillary lateral incisors with composite resin crowns.

Croll (1987) described the restoration of "pegged" lateral incisors with "bonded composite resin crown restoration without enamel reduction". He placed the composite resin (either microfilled or hybrid) with a crown form and stated, "some such restorations have been followed for ten years and more with no sign of detachment, cohesive failure of the resin itself, or significant color or dimensional changes".

Frederick (1987) described the fabrication of composite resin crowns in elderly patients with badly decayed teeth. For retention he combined self-threading pins (15, 16, 17) with bonding to enamel and dentine. The core was of P-30 (18), which was referred to as a macrofilled composite, although it appears to be rather a hybrid composite resin (Atmadja, 1986), and it was veneered with a microfilled composite resin Silux (19).

In 1990, Croll described the fabrication of composite resin crowns in a 3-year old boy. He scalloped the incisal edge, prepared

"vertical striations" in the enamel, etched with 40% acid gel for twenty seconds, used a dentine bonding agent Scotchbond 2 (20), placed the composite resin with an acetate crown form (which had been trimmed on a model to reduce the treatment time), cured for 60 seconds lingually, then for 60 seconds "facially", finished with diamonds and a twelve fluted bur, polished with aluminium oxide disks, and then cured each surface for an additional 40 seconds.

It would appear that, paradoxically, in the last decade the interest in composite resin crowns has been waning. The available references are not numerous, and to this author's best knowledge there have been no evaluation studies of VL-activated composite resin (whether macrofilled, hybrid or microfilled) crowns published.

This is unfortunate, as the studies published in the 1970's have not discredited this means of treatment and the main problems of those days (wear, body discoloration and the unpolishable surface) have been dealt with to a considerable degree through the introduction of improved materials.

PRODUCTS:

(1) Adaptic. Johnson & Johnson, New Brunswick, NJ, USA.

(2) Addent XV. 3M Co. St. Paul, Minn., USA.

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

(4) Nuva-Seal. LD Caulk Co. Milford, Del., USA.

(5) Dycal. LD Caulk Co., Milford, Del., USA.

(6) Blendant. Kerr Mfg. Co., Romulus, Mich., USA.

(7) Epoxylite HL-72. Lee Pharmaceuticals, South El Monte, Calif., USA.

(8) Nuva-Fil. LD Caulk Co., Milford, Del., USA.

(9) Nuva-Seal. LD Caulk Co., London, UK.

(10) Nuva-Fil. LD Caulk Co., London, UK.

(11) Concise Composite Enamel Bond. 3M, St. Paul., Minn., USA.

(12) Scotchbond Dental Adhesive. 3M Dental Products, St. Paul. Minn., USA.

(13) Flexacryl. Lang's Dental Mfg. Co. Chicago, Ill., USA.

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

(15) Minim Link-Plus. Whaledent Int., New York, NY, USA.

(16) Minikin Link. Whaledent Int., New York, NY, USA.

(17) Bondent Link-Plus. Whaledent Int., New York, NY, USA.

(18) P-30. 3M Co., St. Paul, Minn., USA.

(19) Silux. 3M Co., St. Paul, Minn., USA.

(20) Scotchbond 2. 3M Dental Products.

2.3. Sequence of steps in direct composite resin crown construction.

1. Decision on whether a direct composite resin crown is indicated.
2. Placement of bases and glass-ionomer cement or composite resin restorations (if required).
3. Prophylaxis.
4. Colour selection.
5. Placement of the pins, post and core (if required).
6. Preparation.
7. Etching.
8. Bonding.
9. Build up and curing of the composite resin crown.
10. Sealing of the gingival margin.
11. Finishing.
12. Polishing.

2.4 CONSTRUCTION OF DIRECT COMPOSITE RESIN CROWNS

2.4.1 Decision on whether a direct composite resin crown is indicated.

2.4.1.1 General rule. There is a general rule which should guide us in the treatment of a patient. Namely: after the treatment, the patient should be better off than he/she was before the treatment.

If a crown is to comply with this rule, it has to fulfil a number of requirements which can be divided into several groups.

2.4.1.2 Mechanical and physical requirements. Mechanically the crown should be strong enough to withstand masticatory forces.

Kampe, Haraldson, Hannerz and Carlsson (1987) measured the forces of "biting as chewing" in the incisor region of the mouth of "young adults" (16 - 18 years of age) to be 65 to 68 N, or between 6.5 and 7 kg.

While these figures may not appear high, the compressive stresses may be considerable, as the forces tend to be applied over small areas, and may be applied very rapidly, particularly if there is a small and unexpectedly hard object in the food bolus. In addition, there is great reserve strength in the muscles of mastication. The maximal bite force in the "subjectively best biting position" varied between 516 and 532 N (ibid.), and the greatest recorded bite strength exerted by the mandible was 4,343 N (Gibbs, Mahan, Mauderli, Lundeen and Walsh, 1986). This reserve strength comes into play particularly in parafunction.

Wear resistance of the crown should be similar to that of enamel. Enamel is rather wear resistant. Lambrechts, Braem and Vanherle (1987) measured the occlusal contact wear of enamel on premolars and molars and found it to be 23 micrometres and 39 micrometres per year respectively. A low wear resistance would lead to the loss of contour and eventual perforation of the crown. Wear resistance which is too high would lead to traumatic occlusion and may cause increased wear of the opposing tooth.

The thermal expansion of the crown should be similar to that of a natural tooth (Tab.1). Dissimilarity in thermal expansion can contribute to microleakage (penetration of fluids, bacteria and oral debris along the interface between the restoration and the tooth), the disintegration of the luting agent, and the loosening of the restoration (Phillips, 1982, p. 54, 58).

Dentine and enamel have low thermal conductivity and thermal diffusivity (Tab.1), and can be described as effective thermal insulators (Phillips, 1982, p. 53). Materials with high thermal conductivity and diffusivity may insufficiently protect the pulp against thermal insults.

The radiopacity of the crown should be such that it would allow the detection of secondary caries or marginal discrepancies. No clinically based data exist on the degree of radiopacity needed for radiographic evaluation (Lambrechts, Braem and Vanherle, 1987; Stanford, Fan, Schoenfeld, Knoeppel and Stanford, 1987). However, it has been suggested that, for class II composite resins, the radiopacity should be "at least" slightly higher than that of enamel (Lambrechts, Braem and Vanherle, 1987).

The metals used in the manufacture of crowns should not

produce electrogalvanism. Apart from somewhat controversial (Molin, 1990) discomfort for the patient, galvanic currents cause electrolytic corrosion (Phillips, 1982, p. 295-6).

Mechanical properties of the crown should not be adversely affected by the age of the crown, as the crown is rightly expected to serve the patient for a number of years. As the chemical reactions between the materials of the crown and any component of the oral environment may adversely affect the mechanical properties of the crown, the materials of the crown should be chemically inert.

2.4.1.3 Biological requirements. The materials and procedures used in the construction of a crown must not be detrimental to the tooth, oral cavity or systemic health. This obviously rules out materials which are toxic, or carcinogenic, or which require conditions (such as temperature) incompatible with tissue health. The materials should also be free of agents with sensitising potentials (Phillips, 1982, p. 59).

The crown should not damage, but should protect the tooth and periodontal tissues (Ryge, 1978, p. 367). It should be orthodontically acceptable, should not interfere with mastication, and should not be detrimental to oral hygiene. How the crown would meet these requirements depends to a considerable degree on its mechanical properties. For example, a low wear resistance may lead through the loss of anatomical form to reduced masticatory efficiency, over-eruption and tilting of teeth, premature contacts and occlusal interferences (Bryant, 1987), and through the loss of the surface finish to increased accumulation of plaque (Swartz and Phillips, 1957; Larato, 1972; Shafagh, 1986).

These qualities should be of a long term nature, as the exposure of the organism to the crown is to be of a long term nature. This requires chemical inertness (Smith, 1982, p. 13-5).

2.4.1.4 Aesthetic requirements. What is beauty? The Macquarie dictionary (1981, p. 189-90) defines it as "that quality or characteristic which excites an admiring pleasure or delights the eye or the aesthetic sense." Obviously there are two sides to the issue - one is the crown itself, the other is the beholder.

The appearance of the crown consists of several components, namely its position in the mouth, its size, shape, colour and the degree of gloss.

The beholders' views on what is pleasing or delightful are not unchanging. How the ideal of feminine beauty has developed is well shown by Fig.1. On a more dental level, it is well known that in some tribal societies the warriors file down their incisors into pointed, predatory looking shapes. And it was not so long ago that full gold crowns on anterior teeth were considerd a status symbol in certain Asian and European communities.

The current ideal appearance for teeth (which we, being children of the day, consider the only sensible and correct one) is a natural, healthy look, without major irregularities and asymmetries, with restorations as unnoticeable as possible.

Aesthetic considerations in the anterior part of the mouth are so important that, no matter how well the crown stands up to all the other requirements, if its appearance is not satisfactory, the patient will not be happy and the crown will be considered a failure (Shelby, 1976, p. 3-5).

Once again it may be pointed out that the mechanical, biological and aesthetic properties of the crown are mutually dependent. For example, a low wear resistance of the crown may lead to the loss of its form. This, apart from its obvious aesthetic consequences, may also affect its biological properties (2.4.1.3) and marginal gingivitis associated with a plaque collecting crown would not be considered aesthetically acceptable. On the other hand, an aesthetically satisfactory crown may lead the patient "by virtue of pride in his or her appearance" to a higher standard of oral hygiene and better maintenance of the oral cavity (Osborne and Lammie, 1974, p. 374).

2.4.1.5 General considerations regarding indications. Malone, Mazur, Sawyer, Tylman, Henneman and Jameson (1978, p. 128) stated that, "Any complete crown is the last resort in the reclamation of a carious or fractured tooth." This statement can be somewhat modified and paraphrased as: The full crown is indicated when less extensive treatment is unlikely to achieve the desired result. The conditions for which direct composite resin crowns are appropriate lie within this field. The decision as to whether a particular patient, who is to be treated with a crown, is to be treated with a composite resin crown, depends on the peculiar characteristics of different types of crowns.

2.4.1.6 Characteristics and problems associated with different types of crowns according to the materials used in their construction. This subsubsection is not intended to provide a detailed description of different types of crowns, nor of their

construction. For this the reader is referred to a textbook on Fixed Prosthodontics such as Shillingburg, Hobo and Whitsett (1981) or Malone and Koth (1989). Here it is intended to point out those characteristics and problems which should be considered when a decision on indications and contraindications is being made.

Crowns can be and have been made using different materials - metals, acrylic resin, porcelain, castable ceramics, porcelain fused to metal, composite resins.

- Full metal crowns for aesthetic reasons are "rarely if ever" indicated on anterior teeth (Malone, Mazur, Sawyer, Tylman, Henneman and Jameson, 1978, p. 129).

- Acrylic resin crowns should no longer be considered permanenet restorations because of the unsatisfactory mechanical and physical properties of unfilled acrylic resins (1.2).

- Porcelain crowns, while being "the most esthetic" restorations (Kaiser, Malone, Mazur and Howel, 1989, p.189), are susceptible to fractures. Even dental porcelains reinforced with alumina still produce "fragile restorations" (Shillingburg, Hobo and Whitsett, 1981, p.125). There are many who regret the displacement of porcelain jacket crowns with metal ceramic crowns. However, a fractured porcelain crown is an unpleasant experience for both the patient and the dentist. At present, porcelain crowns cannot be permanently repaired (2.4.8.7). While the wear of different materials in the oral cavity is a very complex process, influenced by many factors of which the hardness of the materials is only one, it needs to be noted that dental porcelain is a very hard material. The Knoop hardness number for dental porcelain is 460 (Craig, 1989, p.487).

- Castable ceramics (glass-ceramics) are stronger. The compressive strength of conventional dental porcelain is around 350 MPa (McLean and Hughes, 1965), while that of castable ceramics is in excess of 500 MPa (Sumii, 1988). The transverse strength of conventional dental porcelain is between 62 and 90 MPa (Craig, 1989, p.487), while that of castable ceramics is around 152 Mpa (ibid., p.490). In addition, with a Knoop hardness number of 362 (ibid.), castable ceramics are much softer than conventional dental porcelains and not far distant, in this regard, from enamel (Tab.1).

Unfortunately, crowns made of castable ceramics have aesthetic problems. Being cast, they tend to be of homogeneous colour. Surface staining cannot completely imitate those components of colour which come from the depth of the crown, and one also wonders about the stain's permanency on the surfaces exposed to attrition and abrasion. The answer perhaps lies in casting only the core of the crown and baking onto it a properly coloured body (Sumii, 1988). Unfortunately, this would probably lead to a reduction in the strength of the crown as a whole, and, as the complexity of the construction of the crown increases, so does its cost. In addition, it also causes an increase in the surface hardness. Palmer, Barco, Pelleu and McKinney (1991) found that, in vitro, a castable ceramic (1) with "shading porcelain" caused significantly greater wear on opposing enamel than both a conventional dental porcelain (2) and the castable ceramic without shading porcelain. On the basis of this they suggested that "castable ceramic with shading porcelain should not be used in regions that will function against opposing natural teeth".

- The porcelain fused to metal crown (metal ceramic crown or ceramometal crown) is a highly satisfactory means of treatment. Aesthetically, it is second only to the porcelain jacket crown and perhaps to the porcelain crown built on a cast ceramic core (Sumii, 1988). Its other favourable characteristic is that it tends to collect less plaque than natural teeth. Chan and Weber (1986) studied the plaque index (Silness and Löe) of different types of crowns and compared it with the plaque index of the quadrant, which they set at 100%. The crown/quadrant index for ceramometal crowns was 90%, for natural teeth 110%, for cast gold crowns 148% and for acrylic crowns 152%. The ceramometal crown also appears substantially stronger than the porcelain jacket crown or the castable ceramic crown. Josephson, Schullman, Dunn and Hurwitz (1985) found that ceramometal crowns (3) fractured at loads 3.51 times greater than porcelain jacket crowns (4). Vrijhoef, Spanauf and Renggli (1988) found that the failure load of ceramometal crowns (5) was 3.4 times greater than the fracture load of castable ceramic crowns (6). However, they found that castable ceramic crowns had, at the inner surface, gross surface porosities, which could have resulted from a technical error. They speculated that these porosities may have reduced the strength of the castable ceramic crowns by 33% to 50%.

Unfortunately, the porcelain fused to metal crown has its problems. It requires a substantial reduction of the tooth. This limits its indications in young patients with large coronal pulps and makes the construction difficult on small teeth. Even outside of these categories, the amount of tooth reduction for a metal ceramic crown may be a cause for concern. For the pulp, the gentlest

preparation would be the one leaving the dentine covered with enamel. With the metal ceramic crown this may be achieved lingually, elsewhere the preparation would generally penetrate into dentine. The minimum thickness of the noble alloy coping for a metal ceramic crown is 0.3 mm and of the base alloy coping 0.2 mm. The "absolute minimum thickness" of porcelain is 0.7 mm (Shillingburg, Hobo and Whitsett, 1981, p. 423-4).

Porcelain is more wear resistant than natural teeth. While wear is a very complex mechanism (1.5.1.5) which does not depend solely on hardness, it is interesting to note that the Knoop Hardness Number for porcelain is 460, for enamel 343, and for dentine only 68 (Craig, 1989, p.100).

The metal part of the crown in the presence of other metals in the mouth can produce galvanic currents, leading to electrogalvanic corrosion and to electrogalvanism (Phillips, 1982, p. 295-6, 299-301).

Sometimes the fit of the crown is unsatisfactory, even though the coping fitted well. The problem is probably caused by the high temperature creep of the metal component of the crown (ibid., p. 528).

The porcelain of the ceramometal crowns is susceptible to fracture (Koth, 1989, p. 428) and, at present, cannot be permanently repaired (2.4.8.7).

The construction of the metal ceramic crown is quite complicated. Consequently the crown is rather costly.

2.4.1.7 Advantages and disadvantages of the indirect technique of construction of crowns. With the exception of the direct

composite resin crown, and of the amalgam crown (which for aesthetic reasons is not considered for anterior teeth), all crowns are fabricated by the indirect method. This means that they are fabricated outside the mouth, on the die obtained by pouring the impression of the prepared tooth.

The indirect technique of construction "has been a boon to the practice of dentistry" (Shillingburg, Hobo and Whitsett, 1981, p. 221). It allows the use, during the construction, of conditions (such as heat) which intra-orally would be incompatible with tissue health. It enables some parts of the work to be done outside the oral cavity (thus saving the patient's time), and outside the dental surgery (thus saving the dentist's time). And finally, the work on the die is generally done under better conditions of visibilty and access than the work done on the tooth.

However, the indirect method of construction has its disadvantages.

- It increases the number of visits. Generally at least two visits will be necessary - in the interval between them the laboratory work is carried out. This may be inconvenient for the patient.

- The taking of an impression is necessary. However perfect the preparation, the die will be only as good as the impression allows. Very accurate impression materials are available. However, many materials tend to be technique sensitive, and with most of the materials a satisfactory impression is "impossible if the field cannot be kept dry" (Kafalias, 1961). The methods of keeping the field dry, such as the gingival retraction and electrosurgery, require local anaesthesia. This, as well as the gingival retraction

and the impression itself, may cause problems in some medically compromised patients (AIDS, Haemophylia, Infective Endocarditis, etc).

- In between the visits a temporary crown is required. It usually leaves something to be desired aesthetically. The greatest problem is the retention of temporary post crowns in those unfortunate cases, where all the coronal part of the tooth has been lost. They may become loose if cemented with a temporary cement. If cemented with a permanent cement, they are extremely hard to remove.

- The involvement of the laboratory may present logistic and communication problems. The quality of the laboratory work is one of the determinants of the quality of the crown.

- The increased amount of work and increased consumption of materials in the surgery, as well as the addition of laboratory fees, increase the price of the final product - the crown.

2.4.1.8 Favourable characteristics of the direct composite resin crown.

- The construction of a direct composite resin crown does not require anaesthesia and gingival retraction, which may be of relevance in certain medical situations.

- The direct composite resin crown requires only limited removal of dental tissues.

- The direct composite resin crown is simpler and less time-consuming to construct and requires fewer visits by the patient than the indirect crowns.

- The direct composite resin crown can be repaired and its repair is relatively easy.

- The direct composite resin crown can be constructed and repaired without the use of a dental laboratory.

- The direct composite resin crown is relatively cheap, particularly since its construction is less time-consuming than construction of indirect crowns.

2.4.1.9 Unfavourable characteristics of the direct composite resin crown.

- At present there are no long-term studies of direct composite resin crowns available. Indeed, long-term clinical experience with some of its components (particularly with the bonding agents) is at present lacking. It appears that the direct composite resin crown is adequate when short or medium longevity is required. Beyond that lies an "uncharted territory".

- The direct composite resin crown is inferior to metal and metal-ceramic crowns in its mechanical properties.

- The main means of retention of the direct composite resin crown is by bonding. However, of the many kinds of surfaces to which it may be bonded, at present only enamel appears reliable in the long-term.

- Some components of composite resin have allergenic potential.

- Composite resin restorations have been associated with oral lichenoid lesions.

2.4.1.10 Indications for a direct composite resin crown. The direct composite resin crown is an appropriate mode of treatment if:

- the manipulation of the gingiva which occurs during impressions is to be avoided (e. g. patients with leukaemia,

patients in danger of infective endocarditis),

- the patient or the tooth may not tolerate an extensive preparation or impression (e. g. young patients, mentally handicapped patients),

- the crown needs to be constructed at one visit (e. g. country patients, patients urgently needing crowns),

- the tooth to be crowned appears to have limited life expectancy (e. g. the deciduous teeth, teeth with little periodontal support),

- the patient appears to have limited life expectancy (e. g. patients with terminal ilnesses),

- the crown is likely to be repeatedly damaged (e. g. young patients involved in contact sports, accident-prone patients),

- dental laboratory services are not available,

- the cost is of importance (e. g. patients who cannot afford more costly crowns, patients for whom more costly crowns are not warranted).

2.4.1.11 Contraindications to a direct composite resin crown. The direct composite resin crown is not an appropriate mode of treatment if:

- the crown will have to resist heavy mechanical forces (e. g. on posterior teeth, in patients with parafunctions),

- the long-term survival of the crown is required and the tooth to be crowned does not have adequate enamel present (e. g. the teeth with large areas of exposed dentine, the teeth with large gold inlays),

- the patient is suspected of being sensitive to any component

or by-product of composite resin crown (e. g. BIS-GMA, formaldehyde),

- the patient suffers from oral lichenoid lesions.

PRODUCTS:

(1) Dicor. Dentsply, Inc., York, Pa., USA.

(2) Vita porcelain. Unitek Corp., Monrovia, Calif., USA.

(3) Ceramco porcelain. Ceramco Inc., East Windsor, NJ, USA.

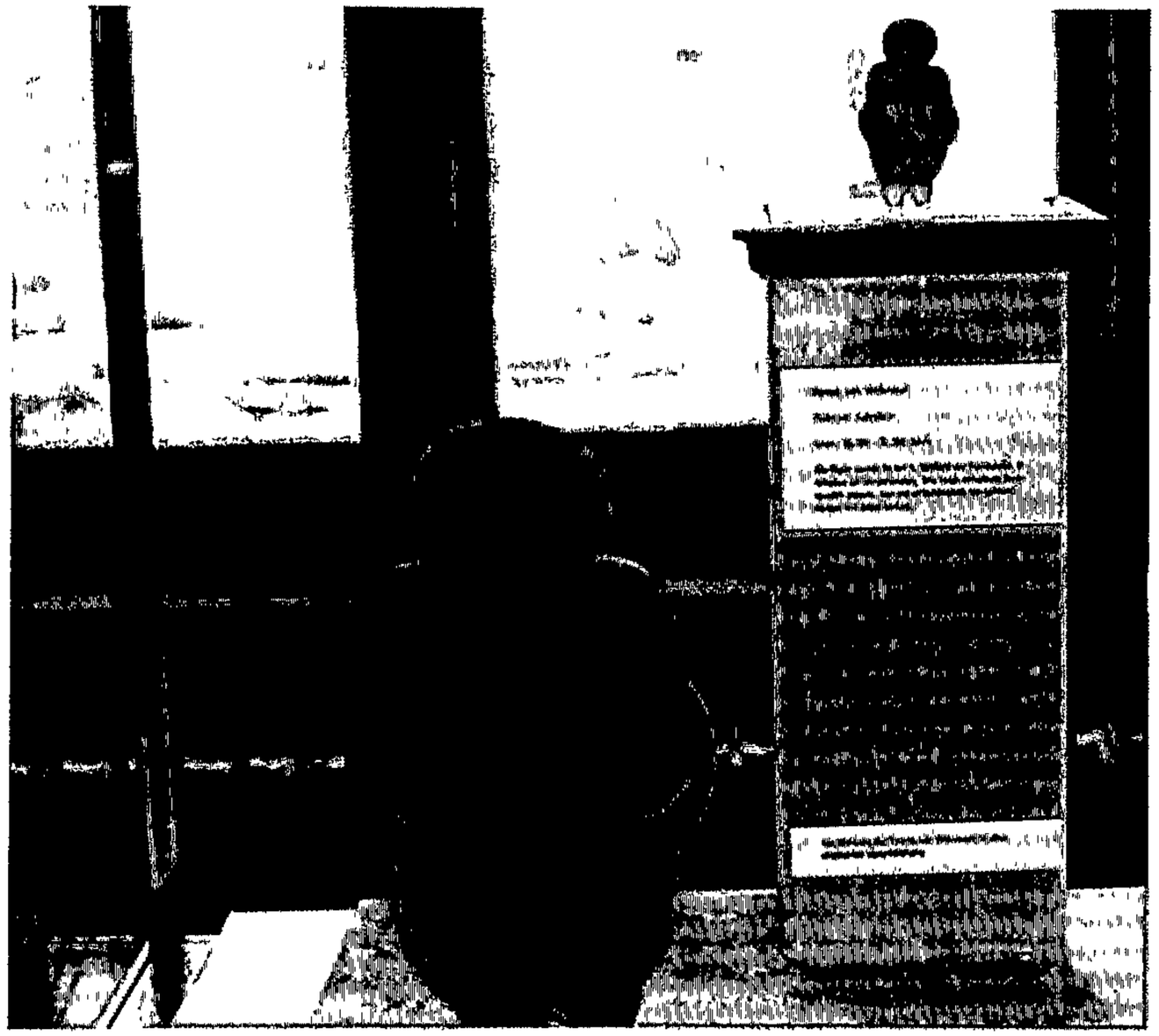
Jel-star metal. J. F. Jelenko Co., Armonk, NY, USA.

(4) Ceramco porcelain. Ceramco Inc., East Windsor, NJ, USA.

(5) VMK 68 porcelain. Vita Zahnfabrik, Bad Säckingen, FR Germany.

Gold-palladium alloy. Elephant, Hoorn, The Netherlands.

(6) Dicor. De Trey/Dentsply, Wiesbaden, FR Germany.



1.1

1.2

Fig.1 - Ideals of feminine beauty. 1.1 - The ideal 20,000 to 30,000 years ago. Enlarged model - the original in UR corner. (Naturhistorisches Museum. Vienna, Austria.) 1.2 - The ideal ca 2,000 years ago. (Museo delle Terme. Rome, Italy.)

2.4.2 Colour selection.

2.4.2.1 Prophylaxis. The teeth should be given thorough prophylaxis prior to colour selection. "Proprietary prophylaxis pastes containing oil or fluoride should not be used" (Low and Majid, 1979). It is recommended that flour of pumice mixed with distilled water be used. Care should be taken not to injure the gingiva, as even slightly injured gingiva may be a source of considerable vexation as far as moisture control is concerned. A rubber cup is less likely to cause this problem than a prophylactic brush (Pus and Way, 1980). In addition, prophylaxis with a rubber cup causes significantly less enamel loss than prophylaxis with a rotating prophylactic brush (ibid.).

2.4.2.2 Colour selection. Colour selection should be done before the placement of the rubber dam. Teeth dehydrate under rubber dam, which makes them appear lighter (Larson, 1986). While the clinical significance of this may be questioned, since during the colour selection the teeth should be kept wet, the rubber dam would also provide a somewhat unnatural background.

As mentioned earlier (1.5.3), the commercially available shade guides are not entirely satisfactory and should be used only for preliminary selection. During the use of the shade guide, both the tab and the teeth should be wet to have the same surface reflectance (Larson, 1986). Surface reflectance can affect the apparent value, in that objects with high surface reflectance appear bright (Preston and Bergen, 1980, p. 46). The selection of value is more important than the selection of hue (Larson, 1986).

The retina of the human eye has two main kinds of photoreceptors: rods (which are responsible for interpreting brightness) and cones (which are responsible for interpreting hues). The cones are located in fovea centralis and function only at higher light levels (Preston and Bergen, 1980, p. 20). It is often suggested that the dentist begin the colour selection by looking at the patient from the corner of the eye, or squinting, so that he primarily use the rods, which enables him to judge the value more correctly.

Normally more than one hue will be selected for a crown: the gingival, which may be yellow or orange, and the incisal, which particularly in young patients may appear blue, violet or gray (Larson, 1986). The canines often have the same hue as the incisors but a higher chroma. The chroma of teeth tends to increase also with the patients' age (Cook and McAree, 1985). Hues are perceived by the cones in the retina through the mechanism of visual pigments. When focusing on a colour these pigments get depleted rapidly, which leads to "hue adaptation" with a loss of discrimination (Preston and Bergen,1980, p.28) To reduce hue adaptation, viewing should be limited to intervals of 5 seconds. The perception of tooth colour can be enhanced by looking at a blue surface (ibid.)

The perception of colour depends also on the light source (Shillingburg, Hobo and Whitsett, 1981, p. 434). Natural daylight tends to be variable, changing with the hour of the day, season of the year, cloud cover and the degree of atmospheric pollution (Preston and Bergen, 1980, p. 26). Artificial light sources often suffer from unequal distribution of light energy. Incandescent lights are predominantly red-yellow, while fluorescent lights are

too high in blue-green energy (Shillingburg, Hobo and Whitsett, 1981, p. 436). There are "colour corrected" lights available, having more uniform distribution of light energy across the visible spectrum, the wavelengths of which range from 380 nm to 760 nm (ibid., Preston and Bergen, 1980, p. 4). While this approaches the light energy distribution of the natural daylight, it has to be recognised that, in addition to variations in natural daylight, the patient may also from time to time be illuminated by uncorrected lights, which may give rise to metameric effects.

"Metamerism is the phenomenon of an object appearing to be different colours when viewed in different light sources" (ibid.). Metamerism was discussed above (1.5.3). While it cannot be completely eliminated, its effects can be minimised by carrying out colour selection under more than one type of light, and the lifestyle of the patient should obviously be taken into account.

After the composite resins have been selected, it is advisable to check the selection by curing them on an unetched tooth surface. It has to be remembered that polymerisation continues for some time after the actual "light cure", leading to an additional "lightening of the colour" (Atmadja, 1986). It is also wise to show the final choice to the patient and ask for his/her opinion.

Clinical recommendations. Prior to colour selection, prophylaxis with flour of pumice in water applied with a rubber cup should be carried out. The colour shade guides supplied by the manufacturers are adequate only for the preliminary selection. When they are used, both they, and the teeth, should be wet. At least two shades (gingival and incisal) should be selected. The selection

should be confirmed by curing small samples of selected composite resin on unetched teeth. The selection should be done under at least two different light sources.

2.4.3 Preparation of enamel.

2.4.3.1 Extent of the preparation. While there is little doubt that carious enamel (and dentine) have to be removed, there is some controversy regarding the need for the preparation of sound enamel and the extent of this preparation.

Some authors use no preparation at all (Ward, Buonocore and Woolridge, 1972; Buonocore and Davila, 1973; Meurman and Halminen, 1974; Lamb, 1974; Watkins and Andlaw, 1977; Croll, 1987).

Others recommend different degrees of enamel preparation: vertical and horizontal crosshatching of the labial and lingual enamel (Bizga, 1974), a shoulder around the fracture site to a depth of one third to one half of the enamel thicknes and extending 1 to 2 mm gingivally, with a "scallopped margin at the gingival aspect of the preparation" (Rule and Elliott, 1975), removal of "1.0 - 1.5 mm" layer of enamel from the labial surface (Roberts, 1976), a "long bevel" (Fuller and Denehy, 1976), a bevel extending "approximately 1.5 mm above the fracture line" (Flynn, 1977), "1-2 mm beveling of the enamel edges" (Ulvestad, 1978), a "half-enamel preparation 1.5 - 2.0 mm wide all around the fractured edge" (Low and Majid, 1979), slight roughening of the enamel surface to be etched (Mufson, Bassiouny and Torreti, 1982), "a long chamfer right around the tooth" with an extra long bevel labially (Exner, 1984), a "chamfer-shoulder" involving "at least half of the enamel thickness", 1 mm wide around the entire enamel periphery for incisal fractures and enamel surfaces only "lightly disked" for peg laterals (Jordan, 1986, p. 80).

There are good reasons for preparing the enamel. At an

unbevelled cavosurface margin, the enamel prisms run longitudinally or obliquely (to the wall of the cavity) and the application of etchant most commonly leads to the dissolution of the peripheries of the prisms. The retention sites (for the resin) thus created are unlikely to "greatly exceed 3-5 micrometres without some remaining prism cores becoming essentially unattached" (Martin and Bryant, 1984a), as the diameter of the prism heads is about 5 micrometres (Meckel, Griebstein and Neal, 1965). A bevel at the cavosurface margin, however, cuts across the prisms and allows for preferential dissolution of the prism cores. This creates the so-called honeycombed appearance of the surface (Martin and Bryant, 1984a), providing retention sites for the resin tags along the prisms, where the length of the tags may reach 26 micrometres (Jörgensen and Shimokobe, 1975). However, the bevel should be confined to the outer half of the enamel, as in the middle third, and particularly in the inner third, of the enamel the prism orientation deviates from the perpendicular to the surface (Buonocore, 1981). The rounding of the bevel-cavity and bevel-surface angles would reduce the danger of the cavity margin being visible through the composite resin, and would also reduce the stress concentration around the cavity margin (Eriksen and Buonocore, 1976a).

Away from the cavosurface margin, on the intact surface of the tooth, a layer of prismless enamel was found on all deciduous teeth and on about 70% of permanent teeth (Ripa, Gwinnett and Buonocore, 1966). This layer averaged 30 micrometres in thickness and was found to cover the entire proximal surfaces of the deciduous teeth, whereas on the buccolingual sections it extended beyond the gingival third only in 86% of teeth. On permanent teeth it extended

beyond the gingival third in only 43% of cases (ibid.) It was also found on the unerupted teeth, thus indicating that it was not acquired post-eruptively. Indeed Ripa, Gwinnett and Buonocore (1966) speculated that the lack of prismless enamel on the buccal and lingual surfaces may be due to wear.

Etching of prismless enamel produces loss of tissue, but no rod patterns (Gwinnett, 1973). Extending the etching time (with 37% phosphoric acid) did not alter this unsatisfactory appearance (Martin and Bryant, 1984a). Brännström, Nordenwall and Malmgren (1978) found no significant difference caused in the SEM appearance of the etched surfaces by mechanical pretreatment (grinding at low speed for "a few seconds" with a diamond point or a medium aluminium oxide disk). However, the surfaces etched came probably from the middle thirds of the buccal surfaces which may not have contained prismless enamel. In addition, it is not clear how much enamel was actually removed. Galil and Wright (1979) found that the "most consistently favourable etches were seen when 140 to 150 micrometres of enamel were removed." Although Nathanson, Bodkin and Evans (1982) found no difference in etching patterns in surface and subsurface enamel, it is not clear from their article, whether the surface enamel was actually prismless enamel (the surfaces studied being the labial surfaces of permanent incisors). Conniff and Hamby (1976) found that the mean pressure required to fracture the bond between composite resin and etched prismless enamel was only 74% of the pressure required to fracture the bond between the same composite resin and prismatic enamel. They performed the test on primary teeth and found also that cleaning the enamel surface with pumice was not sufficient to remove the layer of prismless enamel.

However, how deep should the preparation be? A number of authors maintain that the optimal thickness of the preparation is a half of that of the enamel, but the basis for this opinion is not clear. The thickness of the enamel on anterior teeth varies from about 200 micrometres to over 1600 micrometres (Shillingburg and Grace, 1973). While prismless enamel should be removed, it should be remembered that the organic content of enamel increases as one approaches the dentino-enamel junction. This is due mainly to micropores caused by the irregular arrangements of the prisms (Fejerskov and Thylstrup, 1986, p. 77) and to the presence of enamel spindles and enamel tufts, which may extend into enamel for some 200 micrometres (ibid, p. 77-81). An additional point is the fact that "in the inner half to two thirds of the enamel the prisms follow a wavy course" (ibid, p. 85), and consequently may not run perpendicular to a prepared surface at this level. While all this should have a negative influence on bond strength, a study by Olsen, Duke and Norling (1988) found no significant influence of the depth of enamel reduction on the shear strength of the bond. However, it should also be remembered that enamel can act as a semipermeable membrane (Sharawy and Yaeger, 1986, p. 45), and it is reasonable to assume that its permeability increases with its decreasing thickness. While the above argues in favour of minimal enamel preparation, often the depth of the preparation needs to be increased in order to avoid overcontouring or showing a heavily discoloured tooth through the restoration.

As for the surface extent of the preparation, from the mechanical point of view both retention and resistance need to be considered. According to Shillingburg, Hobo and Whitsett (1981, p.

79), "Retention prevents removal of the restoration along the path of insertion or long axis of the tooth. Resistance prevents dislodgement of the restorations by forces directed in an apical or oblique direction and prevents any movement of the restoration under occlusal forces."

Recommendations for preparation with regard to retention are based on the work of Jorgensen (1955), who studied the relation between the retentive force and the convergence of the axial walls of the preparation. Retention decreased with the increasing convergence angle, and there was a very rapid drop in retention as the convergence angle increased to 10 degrees. Shillingburg, Hobo and Whitsett (1981, p. 79) recommend a convergence angle of 6 degrees.

However, while it has been found that in clinical practice these values are usually exceeded, with the convergence angle being 15, 20 or more degrees, the restorations still remain successful (Leempoel, Lemmens, Snoek and van't Hof, 1987; Nordlander, Weir, Stoffer and Ochi, 1988). The reason is probably that loss of restoration along the long axis of the tooth can normally be caused only by adhesive food and the forces of this adhesion are not great. Caldwell (1962) examined the adhesion of over seventy foods to teeth and found that, with the exception of caramel (0.26 MPa) and toffee (0.19 MPa), the values ranged between 0.005 MPa and 0.11MPa. While the adhesion of foods to enamel and to composite resin may and probably does differ, it is interesting to note that the values of adhesion achieved in enamel bonding are greater by more than two orders of magnitude.

Insufficient resistance is a much more serious problem, as the

occlusal forces can be considerable. The greatest recorded bite strength exerted by the mandible was 4,343 N (newtons - or 443 kg) - the subject was a 37 year old man with a bruxing-clenching habit (Gibbs, Mahan, Mauderli, Lundeen and Walsh, 1986). While this is exceptional, Kampe, Haraldson, Hannerz and Carlsson (1987) found, in a group of 29 young adults, that the mean maximal bite force (in the most comfortable position in the mouth) was 516 - 532 N, and the forces of "biting as when chewing" in the incisor region were 65 - 68 N. It appears that occlusal forces somewhere between "biting as when chewing" and "maximal bite force" are capable of exerting pressures equal to the values of enamel bonding. In order to resist them, the restoration has to be supported by a prepared abutment.

The resistance of a preparation depends on its length, diameter and convergence angle (Weed and Baez, 1984). If a preparation for a composite crown is to stay within the enamel, the modification of the diameter of the tooth and of its shape is obviously limited. However, the length of the preparation can be extended to the vicinity of the gingival margin. Although Weed and Baez investigated the influence of the convergence angle on the resistance, from their work it is clear that, all else being equal, longer preparations offer more resistance.

The resistance form of a preparation was also studied by Parker, Gunderson, Gardner and Calverley (1988). According to them, the centre of rotation (of the restoration being dislodged) is on the margin of the side towards which the rotation takes place, and the farther apically this centre is positioned, the more resistance is provided by the opposite side. In the case of an upper incisor, the more apically the labial margin is placed, the more the palatal

surface of the preparation resists the displacement of the crown in the labial direction.

A paradoxical result was achieved by Bagheri and Denehy (1983), who found that the length of the bevel (beyond 1 mm) - and therefore the length of the preparation - had no significant influence on the force required to displace the restoration. It is possible, however, that none of their preparations provided resistance. In addition, the authors did not state what kinds of failures occurred.

2.3.2.2 Gingival margin. While it is possible that adequate resistance and retention will be provided if the preparation is limited to the incisal half (or less) of the crown, the aesthetic advantages of the crown margin crossing through the highly visible labial surface of the anterior teeth are questionable. However, it is generally accepted that the margins of direct composite resin crowns should remain supragingival.

The main reason for the supragingival placement of the crown margins is the health of the gingival tissues. Subgingival discrepancies between the crown margin and the natural tooth structure may be difficult to identify, difficult to correct, and difficult to clean. Orkin, Reddy and Bradshaw (1987), in a study of 423 "upper middle class" patients with crowns, found that crowns with subgingival margins had higher mean plaque index than the crowns with supragingival margins. "Gingival tissues tended to bleed 2.42 times more frequently with subgingival margins and have a 2.65 times higher chance of gingival recession." (Ibid.) The crowns they studied were indirectly fabricated of gold, porcelain, "nonprecious" and acrylic.

The directly fabricated composite resin crown presents some additional problems: difficulties with achieving a dry field in the gingival sulcus, possible lack of enamel and difficulties with finishing/polishing the margin (regarding both its identification and instrumentation).

There is little doubt that superior aesthetic results would be achieved with the crown margin placed subgingivally. However, it should be realised that a substantial number of gingival margins even on anterior teeth are not normally shown. Crispin and Watson (1981) found that a "normal smile" does not show the gingival margins of upper central incisors in 50% of patients, the figures for upper lateral incisors and upper cuspids being 33.7% and 44% respectively. In the lower anterior teeth, the percentages of patients not showing the gingival margins were 88.8% for the lower central incisor, 88.2% for the lower lateral incisor and 93.4% for the lower canine. In addition, a survey of patients' attitudes (Watson and Crispin, 1981) found that while 73.6% of patients said they would object if the margins showed while they smiled, 63.8% said they would prefer optimum health potential to optimum aesthetics. This matter obviously needs to be discussed with the patient before the formulation of the treatment plan.

If the gingival margin is placed from 0.5 to 1mm from the gingival crest, it is observable and the composite may be finished without damaging the gingival tissues. However, especially if the colour match is good, it may still be difficult to identify the margin and the finishing attempts at the suspected margin may lead on the one hand to damage to extramarginal enamel and submargination, or on the other hand to areas of extramarginal

composite left behind (Clark, Warren and Boyle, 1988). Torstenson, Brännström and Mattson (1985), while studying a method for sealing composite resin contraction gaps, found that a double liner system (1) painted on the tooth surrounding the cavity, prior to the placement of the bevel and the etching, prevented the adhesion of the composite resin to the enamel, so that excess composite resin could be removed with a carver. Grego (1985) described a method whereby a brown wax pencil was used to mark the outline of the cavity, the line with the pencil being made 1 mm from the cavosurface angle, after the preparation and etching. Clark, Warren and Boyle (1988) described a method whereby a thin layer of nail polish was placed on the near-perimeter extramarginal enamel prior to the bevelling and etching. In their in vitro study they found that both marginal discrepancies and damage to the extramarginal enamel were reduced. However, they pointed out that nailpolish contains some ingredients potentially toxic to humans, damaging for the composite resin matrix, and of uncertain effect on the enamel.

The influence of the type of cavosurface margin on microleakage is somewhat controversial. Retief, Woods and Jamison (1982) found that microleakage occurred routinely in varying degrees at the gingival margins, regardless of cavosurface preparation, and that the cavosurface preparation had no significant effect on incisal marginal leakage. Hembree (1984) studied 3 types of cavosurface margin: butt-joint, butt-joint modified by bevelling and butt-joint modified by "shoulder" (chamfer). He found that the different types of cavosurface margin did not alter the leakage pattern. However, Crim and Mattingly (1980) found that bevelling (if combined with etching) resulted in a significant decrease in leakage, particularly

at the gingival margin. Moore and Vann (1988) also found that while the bevel did not eliminate marginal leakage, it significantly reduced it.

If removal of more than the superficial enamel is indicated, it is sound practice to prepare a rounded 45-degree bevel in the cavosurface margin, as this will cut across the enamel prisms - particularly considering their apical inclination in the cervical region (Swancar, 1986, p. 246) - and will provide for better etching and bonding than a butt margin. Bevelling also removes the "crazed or disrupted enamel at the cavosurface angle" (Black, Retief and Lemons, 1981). If only superficial enamel is removed, the margin should be featheredged. Eriksen and Buonocore (1976a, 1976b) found that featheredged margins exhibited consistently reduced microleakage.

Aker, Aker and Sorensen (1979) studied the influence of methods of enamel preparation on the retention of composite resins and found that if the enamel surfaces were prepared with a coarse diamond bur (2), the retentive strengths of composite resin were significantly different (greater) from those obtained on unprepared surfaces, or on the surfaces prepared with a carbide fissure bur (3). An exception was a composite resin used without the unfilled bonding agent (4). Some authors (Weinstein, 1988) recommend medium grit diamond burs for enamel preparation.

The concave part of the lingual surfaces is best prepared with a small wheel diamond (called also a round edge diamond wheel). The labial surface and the lingual surface gingival to the cingulum may be prepared with a tapered diamond (tapered cone diamond bur) (Shillingburg, Hobo and Whitsett, 1981, p. 95, 106, 127, 128). The

same tapered cone diamond bur may be used on proximal surfaces facing edentulous spaces. Where the adjacent teeth are present, the proximal surfaces should not be prepared with diamond cutting disks, which have a tendency to overprepare and whose "potential for injury to the patient is great " (ibid. p. 94). These proximal surfaces are best prepared with metal abrasive strips (5).

Clinical recommendations: After the removal of carious or otherwise unsound enamel and dentine, a 45-degree bevel should be placed through the outer half of the enamel around cavities or fractured areas. The bevel-cavity and bevel-surface angles should be rounded. The enamel should then be reduced to within 0.5 to 1.0 mm of the free gingival margin. The depth of the preparation may be as little as 0.15 mm, but may be increased to avoid overcontouring, or showing a discoloured tooth through the crown. The gingival margin should be featheredged, but with a definite finish line. If deeper preparation is indicated, the gingival margin should be prepared as a rounded 45-degree bevel. A high speed, water cooled coarse, or medium grit diamond drill should be used to carry out the preparation. The preparation of proximal surfaces, if only minimum enamel removal is indicated and if the adjacent teeth are present, should be carried out with coarse or medium grit abrasive strips, rather than with disks.

PRODUCTS:

(1) Tubulitec. Dental Therapeutics AB, Nacka, Sweden.

(2) Coarse diamond bur. Teledyne Dental Products Co., Denver, Col., USA.

(3) Carbide fissure bur. S. S. White Co., Philadelphia, Pa., USA.

(4) Restodent. Lee Pharmaceuticals, South El Monte, Calif., USA.

(5) Horico Steelcarbo Strips. HOPF Ringleb & Co. GmbH & CIE, Berlin, West Germany.

2.4.4 Varnishes and Bases.

2.4.4.1 General considerations. Varnishes and bases are the materials which may be placed between composite resins and the tooth tissues.

The traditional varnish is natural gum dissolved in an organic solvent (Peyton and Craig, 1971 p. 414-416; Phillips, 1982, p. 490). Varnishes are used primarily to provide a barrier against the passage of irritants into dentine (Peyton and Craig, 1971, p. 415).

The term "base" refers to a layer of cement which is used to protect the pulp against mechanical, thermal, chemical and bacterial insults and which should be used "only if the restorative material itself cannot fulfil these requirements." (Krejci, Lutz and Krejci, 1988). It seems reasonable to apply this last comment also in the indications of varnishes.

To the above it needs to be added that the bases containing calcium hydroxide, eugenol or antibiotic are used to medicate the pulp. To discuss their effects and indications would be to go beyond the scope of this treatise. However, it should be mentioned that bases containing eugenol are not indicated under composite resin restorations, as eugenol inhibits the polymerisation of resin (Peyton and Craig, 1971, p. 483; Griffith and Cannon, 1973; Phillips, 1982, p. 498), with a resulting decrease in mechanical properties such as transverse strength (Reisbick and Brodsky, 1971) and hardness (Civjan, Huget and Simon, 1973; DeWald, Moody and Ferracane, 1988).

The physical and mechanical properties of composite resins would appear adequate to protect the pulp from thermal and

mechanical insults (Tab.1), and compare favourably with those of the materials used as bases (Tab.2). The chemical insults attributable to the toxicity of the composite resin are somewhat controversial (1.5.2), but it seems sensible to follow Hume's advice (1988): "All other things being equal, it is obviously more desirable to use a restorative material of low chemical toxicity..." This advice is a specific application of the general rule mentioned earlier (2.4.1.1), which can be applied to any particular property of materials used as bases.

Providing there are no bacteria or their products retained at the time of placement of the restoration, the bacterial insults depend on how well the restorations is "sealed". This in turn depends on how well the composite resin is bonded into the substratum. While good bonding to the enamel is generally achievable (2.4.8.2), bonding to the dentine is a more problematic area (2.4.8.3). Krejci, Lutz and Krejci (1988) found that when subjected to mechanical and thermal stressing, even composite restorations with margins totally in the enamel exhibited fewer excellent (as analysed in the SEM) and more dye penetration prone margins, than if the restorations were not based. This they attributed to the "residual stresses" and the "temperature-dependent volume changes" present in the unbased restorations, as well as to the lack of elastic base, which would absorb the occlusal mechanical load.

It would seem that the ideal base for direct composite resin crowns would be the one which would protect the pulp from the chemical insult of the composite resin, would bond to the dentine, and would have properties allowing a reduction of the bulk of the composite resin, thus reducing the amount of polymerisation

shrinkage and thermal expansion dependent volume changes.

2.4.4.2 Varnishes. Traditional varnishes are not compatible with composite resins as the solvent of the varnish may affect the composite. In addition, the residual monomer of the composite may dissolve the varnish (Craig, 1985, p.191), although to a different degree for different varnishes (Grajower, Hirschfeld and Zalkind, 1976). There are new, resin-compatible cavity varnishes (1, 2, 3) capable of reducing dentine permeability (Tjan, Grant and Nemetz, 1987). However, the thin film of varnish does not allow for a reduction in the bulk of the composite resin.

2.4.4.3 Calcium hydroxide base. Two calcium hydroxide containing bases, one light-cured and the other chemically-cured, have been examined by Krejci, Lutz and Krejci (1988). They found that the urethane dimethacrylate component of the light-cured calcium hydroxide base copolymerised with the composite resin and the restoration behaved as if it was without a base. The chemically-cured calcium hydroxide base appeared to have a compressive strength that was too low, which led to a greater deformation of the superimposed composite resin in the "in vitro wear" test (the fatigue component of wear was studied through application of 500,000 cycles of perpendicular load of 72.5 N on the occlusal centre of the MOD restorations). The calcium hydroxide base may also interact with composite resins, resulting in grey discoloration (Peyton and Craig, 1971, p. 483). Grajower, Hirschfeld and Zalkind (1974) noted yellow discoloration at the interface of calcium hydroxide base (4) and composite resins. It is also frequently observed clinically that

calcium hydroxide bases are readily dissolved by phosphoric acid etchants, although the clinical significance of the danger of contaminating the etched walls is not clear (Fusayama, 1989). If a calcium hydroxide base is indicated for pulpal reasons, it should be limited to a minimal area (Fusayama, 1987).

2.4.4.4 Zinc phosphate cement. The results achieved with zinc phosphate cement bases, with respect to the marginal adaptation and in vitro wear resistance, appeared better than those achieved with calcium hydroxide bases, but fell short of those achieved with glass-ionomer bases (Krejci, Lutz and Krejci, 1988). This the authors attributed to a somewhat lower compressive strength and a much higher modulus of elasticity of the zinc phosphate cement when compared to glass-ionomer cement. They speculated that the modulus of elasticity of between 5 and 10 GPa (mistakingly stated in the text as 5 and 10 MN/m^2) is the most desirable in a base, allowing for best absorption of occlusal forces.

A further shortcoming of zinc phosphate cement is its lack of adhesion to the tooth tissues (Peyton and Graig, 1971, p.405; Phillips, 1982, p. 463), which means that the cement does not prevent or reduce microleakage, does not reinforce the tooth and does not contribute to the retention of the composite resin. The effect of the zinc phosphate cement base on the pulp is also a matter of concern (Peyton and Craig, 1971, p.410; Phillips, 1982, p. 466, 467).

2.4.4.5 Glass-ionomer cements. The bases performing best in the Krejci, Lutz and Krejci (1988) study were those of glass-ionomer

cement. The invention of the glass-ionomer cement was reported by Wilson and Kent in 1972, although polyacrylic acids were used in the 1960's in the mining, textile, cosmetic and paper-making industries and were known for their binding properties (ibid.). The material was introduced in Australia in 1976 (Personal communication, 1991).

Glass-ionomer cements are "based on the hardening reaction between ion-leachable (calcium fluoroaluminosilicate) glasses and an aqueous solution of homopolymers and copolymers of acrylic acid" (ibid.). Upon mixing, the H+ ions (protons) from the acid penetrate into the surface of the glass particles and displace Ca++ and Al+++ ions, thus degrading the surface layer of the particles into a dehydrated siliceous gel. The cations form metallic salt bridges with the COO- groups of polyanion chains thus causing the aqueous phase to gel. As hydration proceeds, strength is developed (Wilson and Kent, 1972; McLean and Wilson, 1977a; Phillips, 1982, p. 487; van de Voorde, Gerdts and Murchison, 1988; McLean, 1988).

During its setting reactions the cement is very "water-sensitive". If water comes into contact with its surface before it has hardened, the metallic cement-forming ions will be lost, the cement will lose its translucency and its surface will be weakened. On the other hand, if the cement is dehydrated, the loss of water needed for hydration will lead to fissuring and cracking (McLean, 1988).

Where possible, the cement should be placed with a matrix, upon its removal it should be further protected - varnishes have been recommended (Phillips, 1982, p.489). However, a coat of some light-curing bonding agents - particularly those which form a low

contact angle on the glass-ionomer cement, eg Visio-bond (5), or Heliobond (6) would appear to provide better protection (Earl, Hume and Mount, 1985; Earl, Mount and Hume, 1989). This may be left uncured during the initial adjustment, which is best carried out with hand instruments. The coat of the bonding agent should then be replenished and cured (McLean, 1988).

The glass-ionomer cement has mechanical properties (Tab.2) which allow it to be a good material for bases and it can be radiopaque (Tyas, Toohey and Clark, 1989; Mount, 1989b, 1989c). It also has several other attractive properties, which make it a suitable material for the bases of direct composite resin crowns.

a. Glass-ionomer cement adheres to enamel, dentine, stainless steel, and tin or tin oxide plated platinum and gold (McLean and Wilson, 1977a). This bond was found to be in the region of 4 MPa (ibid.). "Although the adhesive bonds at the various interfaces differ, a common feature to all is the bridging of oxygen atoms by an ionic metal link" (such as Ca++, Sn++) (McLean and Wilson, 1977b). More recently, it has been shown (Wilson, Prosser and Powis, 1983) that polyacrylate chains interact with the surface of enamel, displacing phosphate and calcium ions. An intermediate layer is then formed, where the enamel contains polyacrylate and the cement contains displaced phosphate and calcium ions.

Lacefield, Reindl and Retief (1985) studied the tensile bond strength of glass-ionomer cement (7) to untreated, conditioned (50% citric acid, 1 minute) and etched (37% phosphoric acid, 1 minute) enamel, dentine and cementum. They found that etching or conditioning had no significant effect on the tensile bond strength of this cement. The tensile bond strengths they achieved to enamel

(4.18 to 4.96 MPa) were significantly greater than those to dentine (2.51 to 3.33 MPa), which were significantly greater than those to cementum (1.74 to 2.41 MPa).

Powis, Folleras, Merson and Wilson (1982) studied the influence of 15 reagents on the adhesion to enamel and dentine of a glass-ionomer cement (8). They found that a suitable conditioner can enhance the bond strengths significantly, and that the most effective conditioners were solutions containing poly(acrylic acid), tannic acid or surface active solutions. The mean tensile bond strengths to dentine achieved with these reagents were 7.32 MPa with 25% tannic acid and 6.79 MPa with 25% poly(acrylic acid).

Long, Duke and Norling (1986) evaluated the influence of different concentrations of poly(acrylic acid) applied for 30 seconds on the shear bond strength of a glass-ionomer cement (9) to dentine. The 30% and 35% concentrations produced significantly higher values (3.76MPa and 3.89 MPa respectively) than the other concentrations.

Barakat, Powers and Yamaguchi (1988) found that Glasionomer Base Cement (10) achieved generally higher bonding strengths when the dentine was conditioned with poly(acrylic acid) for 30 seconds, compared to those achieved after 10 seconds conditioning.

Aboush and Jenkins (1989) studied the bonding of glass-ionomer cements to amalgam. They found the tensile bond strength to be from 6.1 MPa to 7.92 MPa, which was comparable to the bonding strength to enamel and significantly higher than the bonding strength to dentine. There was no significant difference between the bonding strength to a conventional amalgam (11) and to a high copper amalgam (12).

Glass-ionomer cement can also function as a substratum to which composite resins can be bonded, as will be discussed later (2.4.8.5).

b. Glass-ionomer cements are tolerated well by the pulp. This has been attributed to the poly(acrylic acid) being a weak acid with a large molecule which does not diffuse readily down the dentinal tubules and which has a strong electrostatic attraction between its H+ ions and the polyanion polymer chain (McLean and Wilson, 1977b). This explanation seems somewhat dubious in light of the study by Wang and Hume (1988) which showed that while the dentine was highly effective as an acid buffer, the H+ ions from weak organic acids diffused through it much more readily than the H+ ions from strong inorganic acids. The favourable pulpal reaction may well be a function of the cement's adherence to dentine (which prevents microleakage). The cement itself is not innocuous. Hume and Mount (1988) found that its directly-prepared eluates were highly cytotoxic and concluded, "the glass-ionomer cements would not appear to be desirable materials for placement in direct contact with pulp tissue."

A study by Garcia, Caffesse and Charbenau (1981) showed that well finished glass-ionomer cement restorations (13) are very well tolerated by the gingival tissues.

c. Glass-ionomer cement releases fluoride ions, with an anti-cariogenic effect. Swartz, Phillips and Clark (1984) studied the release of fluoride from six glass-ionomer cements and found it both in the short term (up to 30 days) and in the long term (up to 12 months) to be similar in magnitude to that from a silicate cement (and very much greater that that from a polycarboxylate cement).

Derand and Johansson (1984) studied secondary caries formation (in vitro - caused by acidified gel) and found that the demineralisation zones around glass-ionomer restorations were smaller that those around amalgam, composite resin and ZOE cement restorations. They found some wall lesions associated with glass-ionomer cement restorations. This they attributed to the inadequate seal, which was "probably broken between the dentine and cement." It is not clear from the article, if and how the dentine was conditioned. In 1986 Hicks, Flaitz and Silverstone conditioned the walls and the base of the cavities with polyacrylic acid and found no wall lesions around glass-ionomer restorations. They also found the mean depth of the outer surface lesions adjacent to glass-ionomer restorations to be significantly smaller than that of the lesions in the control group (no restorations).

There are several types of glass-ionomer cements available: Type I are used for luting, Type II are for glass-ionomer restorations and Type III are the fast setting lining materials (McLean, 1988). More recently, light-cured glass-ionomer cements have appeared, such as Vitrabond (14) (Clinical Research Associates, 1988). They are claimed to be stronger and to bond to dentine better than the traditional glass-ionomers. Vitrabond comes as powder and liquid. It contains some HEMA and may be capable of chemical bonding with composite resins. It does not require pretreatment of dentine (ibid., 3M Health Care Group, 1988). Long term clinical evaluation of light-cured glass-ionomer cements is not yet available (Clinical Research Associates, 1988b).

Prior to the fabrication of a composite resin crown, deep cavities should be based with Type II glass-ionomer cements, as it

is easier to apply large amounts directly from the capsule and also because these cements having higher powder/liquid ratio are stronger (Mount, 1989b; Mount, 1989c). Type II is also used to restore all cavities extending onto the cementum, where the bonding obtained by composite resins is likely to be poor (2.4.8.4) - the fluoride releasing property of the glass-ionomer cements is likely to reduce the incidence of marginal caries (Derand and Johansson, 1984; Hicks, Flaitz and Silverstone, 1986). Medium depth cavities, or fractures, where only a relatively thin layer of the base is needed should be based with Type III cement, or with a light-cured glass-ionomer cement, as both these types set faster than Type II (Clinical Research Associates, 1988b; McLean, 1988; Mount, 1989c).

However, Marshall, Marshall and Harcourt (1982) found that Glass-ionomer bases reduced the surface hardness of composite resins. This they ascribed to the presence of the liquid in the freshly mixed glass-ionomer cement. While the clinical significance of this effect has not been established, it is interesting to note that out of four main bases they studied (zinc oxide eugenol, modified zinc oxide eugenol, glass-ionomer and polycarboxylate cements), the polycarboxylate cement base caused the least decrease in the surface hardness of the composite resin.

2.4.4.6 Zinc polycarboxylate cement. The polycarboxylate (or polyacrylate) cement is a powder-liquid system. The liquid is similar to that of glass-ionomer cement - an aqueous solution of polyacrylic acid and copolymers. The powder is similar to that of zinc phosphate cement - principally zinc oxide with some magnesium oxide (Phillips, 1982, p. 471). While its mechanical properties

appear inferior to those of zinc phosphate cement (Tab.2), it possesses some of the qualities of glass-ionomer cement, such as adhesion to the tooth structure and some metals (Mizrahi and Smith, 1969; Ady and Fairhurst, 1973; Phillips, 1982, p. 473, 474), and good tolerance by the pulp (McLean, 1972), but it does not release fluoride ions (Swartz, Phillips and Clark, 1984). It is used mainly for luting rather than as a cement for bases. A search through the Australian Medline network of the Medlars system 1966 to (mid) 1989 files found only 11 articles dealing with the polycarboxylate cement as a material for a base.

Clinical recommendations. Prior to starting the preparation for the composite resin crown caries has to be removed and cavities restored (Fig.2). Very deep cavities (where undetectable exposures of the pulp cannot always be ruled out) should be lined with calcium hydroxide, but the area covered with calcium hydroxide should be small. The lost dentine of these large cavities should be replaced with bases of glass-ionomer cement type II. Cavities of medium depth should be based with bases of glass-ionomer cement type III, or with light-cured glass-ionomer cements. Shallow cavities, just extending into the dentine, need not be based if they are surrounded by sound enamel; the composite resin can be bonded into their pulpal wall (2.4.8.3). All cavities extending to the cementum should be restored with glass-ionomer cement type II. The margin of the composite resin crown will be in this glass-ionomer cement restoration.

PRODUCTS:

(1) Microjoin. Sci-pharm, Duarte, Calif., USA.

(2) Cavi-Line. L. D. Caulk Co., Milford, Del., USA.

(3) Universal. S. S. White Dental Mfg. Co., Philadelphia, Pa., USA.

(4) Dycal. L. D. Caulk Co., Division of Dentsply International, Milford, Del., USA.

(5) Visio-bond. Espe, West Germany.

(6) Heliobond. Vivadent, Schaan, Liechtenstein.

(7) Fuji type II. G-C Industrial Corp., Tokyo, Japan.

(8) LGC Aspa IV. Laboratory of the Government Chemist, London, England.

(9) Ketac-Fil.

(10) Glassionomer Base Cement. Shofu Dental Corp., Menlo Park, Calif., USA.

(11) Amalcap. Vivadent, Schaan, Liechtenstein.

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

(13) ASPA Caps. L. D. Caulk Co., Milford, Del., USA.

(14) Vitrabond. 3M Dental Products Division, St. Paul, Minn., USA.

	ZINC PHOSPHATE	CALCIUM HYDROXIDE	GLASS-IONOMER	ZINC POLY-CARBOXYLATE
COMPRESSIVE STRENGTH MPa	172 (1)	10-27 (1)	71-175 (1)	69 (1)
TENSILE STRENGTH MPa	14 (1)	1 (1)	3.5-4 (1) 2.75-7 (2)	9.6 (1)
MODULUS OF ELASTICITY GPa	20-22 (1)	0.37 (1)	2.2-6.3 (1) 10. (3)	5 (1)
HARDNESS KNOOP	38 (4)	14.5* (5)	60 (6)	?

TAB.2. MECHANICAL PROPERTIES OF MATERIALS USED FOR BASES

(1) Craig,1989, p.218.
(2 Mount, 1989b.
(3) Krejci, Lutz and Krejci, 1988.
(4) Craig, 1985, p. 97.
(5) Onose, 1989.
(6) Phillips, 1982, p.481.

* Light-cured

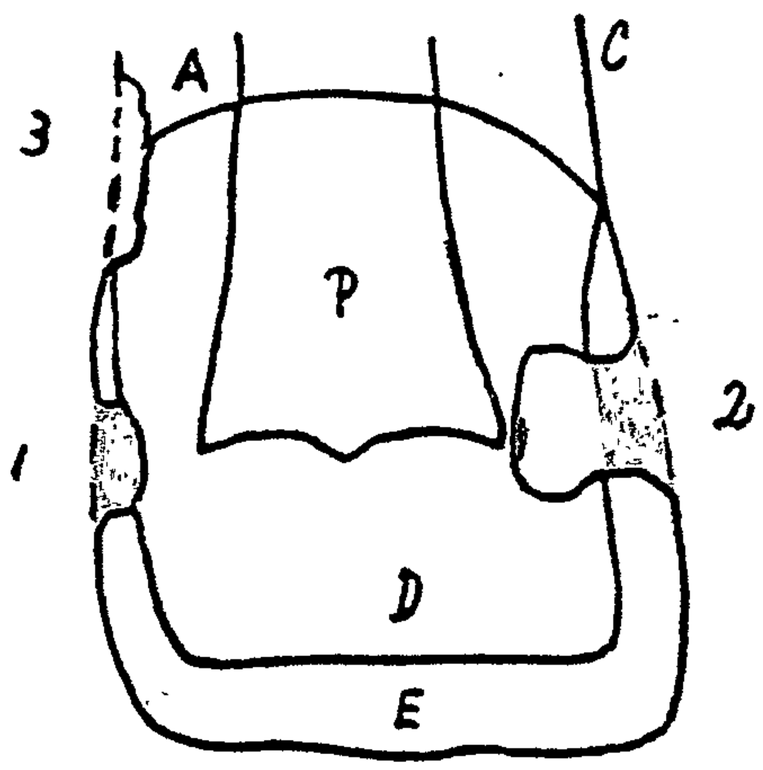


Fig.2 - Restoration of cavities in the tooth which is to have a direct composite resin crown. A - cemento-enamel junction, C - cementum (if to scale its thickness would be up to 1/4 of the thickness of the line), D - dentine, E - enamel, P - pulp, 1 - shallow cavity surrounded by enamel, 2 - deep cavity, 3 - shallow cavity extending onto the cementum. Grey - composite resin, yellow - glass ionomer cement, red - calcium hydroxide.

(Shape and structure of the tooth according to Shillingburg and Grace, 1973; and Wheeler, 1965. Mag. 5x.)

2.4.5 Pins.

Pins are metal pieces, slender cylinders in shape, which may be used as components of tooth restorations. They "have long been popular with the more ingenious members of dental profession" (Wing, 1965). In fact, the earliest reports on the use of pins go back to the middle of the last century (Lustig and Osorio-Jaramillo, 1986). While originally they had been thought to strengthen, or reinforce, the restorations (Markley, 1958), this has been shown to be mostly incorrect with amalgam (Wing, 1965; Duperon and Kasloff, 1973), and partly incorrect with composite resins (Lugassy, Moffa and Hozumi, 1972; Dilts, Podshadley and Neiman, 1973)). They are now used generally to increase the retention of restorations in the teeth.

The pins increase retention of restorations by virtue of being attached to both dentine and restorative material. They can be divided into three groups according to the way they are attached to the dentine (Chan, 1983; Marzouk, Simonton and Gross, 1985, p. 205):

a. Cemented pins. These pins are cemented into over-sized channels.

b. Friction-locked pins. These pins are driven into under-sized channels.

c. Self-threading pins. These pins are screwed into under-sized channels.

The effect of pins on the strength of composite resins may in some instances be favourable. Lugassy, Moffa and Hozumi (1972) found the compressive strength was significantly increased (about 20%) by inclusion of selfthreading pins (1) in the composite resin - the pins extended through the whole length of the specimen and were

parallel to the direction of force. The tensile strength, with the pin at a right angle to the direction of force, was significantly decreased (about 24%). Dilts, Podshadley and Neiman (1973) also found that pins placed parallel to the direction of the compressive force caused an increase in the compressive strength of composite resins, while pins placed at a right angle to the direction of tensile force reduced the diametral tensile strength. The pins did not seem to have a significant effect on the transverse strength. These authors (whose study was somewhat marred by numerical inconsistencies) considered the changes, even when statistically significant, to be too small to be of clinical significance.

The retention the pin can provide depends on its retention in the dentine, on the strength of the pin, and on the retention of the pin in the restorative material.

Moffa, Razzano and Doyle (1969) examined retention of cemented pins (2), friction-locked pins (3) and self-threading pins (1). They found the cemented pins to be the least retentive, the friction-locked pins to be intermediate and the self-threading pins to be the most retentive. For both cemented and self-threading pins there was a significant increase in retention with an increase in their diameter. (They tested only one size of the friction-locked pins.) They also examined how the tensile strength was influenced by the depth of pin embedment and found that it increased with the increased depth. For the cemented pins there was a linear relationship, for the friction-locked and self-threading pins there was less increase beyond 2 mm.

With the self-threading pins, if the depth exceeded 2 mm the pins with the smaller diameter (0.58 mm) fractured, the pins with

the larger diameter (0.79 mm) fractured dentine (ibid.). Lugassy, Moffa and Hozumi (1972) also found that the self-threading pins (1) were frequently fractured at 3 mm embedment.

Retention of pins in composite resins, both microfilled and hybrid, was studied by Butchart, Grieve and Kamel (1988a). They compared Bondent dentine pins (1) which were designed specifically for composite resins with Link Plus pins (1). Bondent pins are inserted 1.5mm into dentine and, depending on length of their "head", either 0.5 mm or 1.0 mm into the composite resin. They found the retention of Bondent pins in the dentine to be "equal to or superior" to that of other pins (the mean tensile force required to remove a pin being 17.15 kg). The retention in the composite resins of the longer Bondent pin (varying from 7.51 kg to 14.66 kg for different composite resins) was about equal to that achieved by the Link Plus pin (7.6 kg to 16.02 kg) and clearly superior to that of the shorter Bondent pin (3.44 kg to 5.20 kg). The authors explained this by better adaptation of the composite resin to the Link Plus pin, as well as by the configuration of the head of the Bondent pins, which may cause shadowing (thus interfereing with the light cure) and which can also concentrate stresses. The variations between the composite resins probably depended on different values for their fracture toughness.

The retention of pins in composite resins also depends on their diameter and the depth of embedment in the composite resin, increasing with increases in their values (Podshadley, 1989).

An interesting study was done by Butchart, Grieve and Kamel (1988b), who compared the retention provided by Bondent (4) pins and by a dentine bonding agent (6). They found that the use of dentine

bonding agent provided higher strength than a combined use of two pins and the bonding agent, which in its turn was higher than that achieved by pins alone. However, for the dentine bonding agent they also etched the enamel and the strength was tested by applying tensile force, while in clinical situations shear strength is probably more relevant.

The two dangers which are probably foremost in the mind of a practitioner utilising pins are pulpal penetration and periodontal perforation. To avoid these it is advisable to prepare pinholes half-way between the outer surface of the tooth and the pulp, as guided by a radiograph (Shillingburg, Hobo and Whitsett, 1981, p. 143). It is a sound practice to follow this advice, even though the actual pulpal penetration and periodontal perforation may be less frequent than feared. Newsome and Youngson (1987), examining 429 cases, found that there were 3 cases of periodontal perforation and 4 cases of pulpal penetration (plus 3 cases of suspected pulpal penetration). Unfortunately, the tooth may be damaged even without these two dramatic occurrences.

Pin insertion induces stresses in the dental tissues. When these stresses exceed the elastic limit of the tissue, deformation of the tissue will occur; when they exceed the plastic limit, fractures will occur (Marzouk, Simonton and Gross, 1985, p.205). Dentinal damage can be caused already by the channel preparation, particularly if the twist drill used is dull (Standlee, Collard and Caputo, 1970). The stresses induced during the insertion of the pin are the lowest for cemented pins, intermediate for self-threading pins, and highest for the friction-locked pins (Marzouk, Simonton and Gross, 1985, p. 206). Further factors favouring dental damage

are: increased diameter of the pin, increased depth of the insertion of the pin, overthreading or overdriving the pin into the channel, reduced distance between threads of the self-threading pin, smaller amount of dentine available, poor quality of dentine (overmineralised or dehydrated), location of the pin in a stress concentration area (e.g. junction between clinical crown and clinical root) or near the dentino-enamel junction (Marzouk, Simonton and Gross, 1985, p.206-7; Caputo and Standlee, 1976; Chan, 1983).

Khera, Chan and Rittman (1978) studied the effect on the dentine when two pins were placed in the same tooth. They found that the interpin distance required to avoid dentine crazing increased with the increased diameter of the pins. The safe interpin distance they recommended for the smallest studied pin diameter of 0.48 mm was 3 mm. For the larger diameter pins they recommended 5 mm as the minimum safe interpin distance.

The cracks in the dentine caused by pins may, on the one hand, communicate with the pulp, resulting in effect in "clinically undetectable pulp exposures" (Jordan, 1986, p.34), and on the other hand, may be accompanied by cracking of the overlying enamel. This may lead to microleakage through this enamel and corrosion of the pin resulting in a typical dark grey or bluish discoloration of the composite resin restoration (Jordan, 1986 p. 34, 35).

Pameijer, Glantz and Mobasherat (1983) studied corrosion (both in vivo and in vitro) of TMS stainless steel pins (7), TMS pins, gold coated (8) and cast gold alloy (9) pins. They found that none of the pins had the same composition before and after tests. The cast gold alloy pins underwent the least compositional changes. The

most pronounced changes occurred in the gold coated pins. This the authors ascribed to imperfection of the coating, with the consequent creation of "pit corrosion" sites, and they questioned the merits of the gold coating. Fewer changes were also found in cemented stainless steel pins compared to the non-cemented stainless steel pins. The authors felt this indicated the favourable influence of the cement.

While Pameijer, Glantz and Mobasherat (1983) used zinc phosphate cement (10) for cementation of pins, it seems sensible to use glass-ionomer cement for this purpose because of its advantageous properties (3.3.3.5). Bass (1986), recommended the coating of self-threading pins with glass-ionomer (11) cement prior to their insertion to reduce the microleakage along the pin-tooth interface, with its potential for pulpal and aesthetic complications. Application of cavity varnish (12) into the pinhole has also been recommended (Moffa, Razzano and Folio, 1968), although it is difficult to see how this can reduce the microleakage if the pin hole is somewhat oval or conical in shape as is often the case (Kayser, Mentz, Snoek and Spanauf, 1983). In addition, Moffa, Razzano and Folio (1968) found that the application of cavity varnish into the pinhole reduced the retention of a cemented pin by 46%. The retention of friction-lock and self-threading pins was not significantly affected. A small amount of calcium hydroxide may be placed at the tip of the pin, particularly if communication with the pulp is suspected (Suzuki, Goto and Jordan, 1973).

Pins made of titanium are also available (13, 14 etc). Titanium is passivated by formation of a selfrepairing layer of oxides on its surface, which makes it corrosion-resistant (Parr, Gardner and Toth,

1985). The Modulus of Elasticity of titanium is lower than that of stainless steel (ibid.; Phillips, 1982, p. 605), and therefore closer to the Modulus of Elasticity of dentine (Tab.1). However, the tensile strength of titanium is also lower than that of stainless steel (Phillips, 1982, p. 605), and it has been shown that in certain circumstances pins may be the weakest link in the pin retained composite resin restorations (Moffa, Razzano and Folio, 1968; Lugassy, Moffa and Hozumi, 1972).

Indications for the use of pins do not appear to have been systematically studied. Marzouk, Simonton and Gross (1985, p.205) state "pins are often required for restoration of mutilated and badly broken down teeth", while according to Jordan (1986, p.34) pins are "rarely indicated in the anterior region". Kayser, Mentz, Snoek and Spanauf (1983) were more specific, stating "pins are generally indicated in vital teeth, where more than 25% of dentine has been lost." This presumably means the loss of dentine in one location on the tooth, but even so, this rule does not appear satisfactory. If, for example, an incisor lost uniformly half of the thickness of dentine from its palatal surface and adjacent halves of the proximal surfaces, more than 25% of dentine would have been lost, yet pins would not be required.

From the mechanical point of view, it is necessary to consider the distance between those points of the restoration on which loads may be applied and the nearest supporting dental tissue. In addition, the size and quality of the supporting tooth tissues, the magnitude of the loads, the mutual angulation of the loads and the supporting tooth tissues and the mechanical properties of the restorative material are all of importance. If the supporting tooth

tissues are defined as those tooth tissues which provide retention and/or resistance for the restoration, it is obvious that the direct composite resin crown has more supporting tooth tisues than the restorations relying on the classical shapes of cavities or on the bevels around the periphery of the fractures. It seems therefore justifiable to be conservative when making a decision on the need for pins, and on the number of pins required, when constructing a direct composite resin crown.

It has been recommended that the minimal number of pins capable or providing adequate retention be used (Chan, 1983). The sites normally recommended are "on the mesial and distal surfaces of the teeth, near the buccoproximal and linguoproximal line angles" (Shillingburg, Hobo and Whitsett,1981, p. 143). Figure 3 shows locations to be considered for the insertion of pins. Figure 3.1 shows locations as suggested by Marzouk, Simonton and Gross (1985, p. 213) For a direct composite resin crown it generally seems reasonable to limit the number of pins to two, inserted where possible in the linguoproximal line angles as shown in Fig.3.2.

An extreme situation has been described by Carter (1983), where practically all supragingival tooth structure is lost and pins are used to retain the core, around which the composite resin crown is built. Carter states, "Three threaded pins will carry a crown, four are better". While his Fig.1 seems to suggest placement in the centre of labial, lingual and proximal surfaces, it would appear more prudent to place the pins in labioproximal and linguoproximal line angles, where their relationship to the pulp may be assessed with the help of radiography (Fig.3.3). It is also advisable to build the core up of a conventional, or hybrid composite resin,

rather then a "microfine" one, as the retention of composite resins by pins depends also on the strength of the composites. Moll, Howe and Svare (1978) found that a composite resin core of conventional composite resin (15) retained by four self-threading pins was significantly stronger than a cast gold post-core.

An alternative to the above suggestion regarding the placement of pins in these extreme cases is possible. Marzouk, Simonton and Gross (1985, p. 212, 213) advise against placing a pin in the middle of the lingual surface, in order to avoid the "cingulum pulp horn". However, when nearly all of the supragingival tooth structure is lost (and the tooth remains vital) the lingual pin is inserted apically to the former location of the cingulum pulp horn. It is also worth noting that according to Shillingburg and Grace (1973) all anterior teeth at the level of the cemento-enamel junction have the thickest wall of dentin on their lingual side. When a pin is placed in the centre of the lingual dentinal wall, the pins in the linguoproximal line angles may be moved somewhat farther labially, to increase the interpin distances as shown in Fig.3.3.

The root canals at the cervical levels tend to be ovoid . The upper central incisors are the only anterior teeth where the longer axis of this ovoid is in the mesiodistal direction (Ingle, Mullaney, Grandich, Taintor and Fahid, 1985, p. 118-33). This situation is shown in Fig.3.3. In other teeth, where the longer axis is in the labiolingual direction, if a core is retained by three pins, the pins from the linguoproximal angles may be moved even farther labially.

A consideration should be given to the use of cemented pins, or self-threading pins of smaller diameter, in the labioproximal

locations, and small teeth (particularly lower incisors) may require a different method of retention.

Clinical recommendations: For the composite resin crown self-threading pins are recommended, as they provide greatest retention. However, when the amount of dentine is inadequate (eg lower incisors), or the strength of the dentine is compromised (eg non-vital teeth), cemented pins may be preferable. The self-threading pins may be sealed with glass-ionomer cement. The minimum number of pins should be used per crown. They should be inserted near the linguoproximal line angles. At the gingival level it is possible to insert a pin in the centre of the lingual surface.

PRODUCTS:

(1) Self-threading pins. Whaledent, Inc., Brooklyn, NY, USA.

(2) Cemented pins. E. A. Beck & Co., Anaheim, Calif., USA.

(3) Friction-locked pins. Unitek Corp., Monrovia, Calif., USA.

(4) Bondent Dentine Pin. Whaledent, New York, USA.

(5) Link Plus Dentine Pin. Whaledent, New York, USA.

(6) Scotchbond. 3M, St. Paul, Minn., USA.

(7) TMS stainless steel pins. Pulpdent Co. Inc., Brookline, Ma., USA.

(8) TMS pins gold coated. Whaledent International, New York, NY, USA.

(9) Jelenko "O". Jelenko Co. Inc., New Rochelle, NY, USA.

(10) Fleck's cement. Mizzy Inc., Clifton, Ver., USA.

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

(12) Copalite. Harry S. Bosworth Co., Chicago, Ill., USA.

(13) MPS. Brasseler USA, Inc., Savannah, Ga, USA.

(14) Filpin. Vivadent (USA) Inc., Tonawanda NY, USA.

(15) Adaptic. Johnson & Johnson, East Windsor, NJ, USA.