A CRITICAL REVIEW OF DENTAL LITERATURE

Concerning

THE PORCELAIN JACKET CROWN

by

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INTRODUCTION

In this critical review an attempt has been made to cover the development of the porcelain jacket crown, from its inception up to the present day.

The Index of Dental Literature was used as a basis for locating the books and articles referred to in the text. The Index itself has certain omissions, and also some of the articles to which it refers are no longer available in Sydney, and hence were not reviewed. The difficulty of locating articles in foreign language journals, and of having them translated, lead to the abandonment of this part of the literature.

Articles which appeared to be merely repeats of earlier work carried out by others have been read but not mentioned or reviewed in the text.

In spite of the above shortcomings, sufficient material remained to provide a fairly comprehensive picture of the historical development and present application of this restoration.

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HISTORICAL DEVELOPMENT OF THE PORCELAIN JACKET CROWN

Lee (267) stated that through the influence of Chinese porcelain, the art of making china and other ceramic wares, was spreading throughout Europe in the early eighteenth century. In 1715 the first white-ware factory was established at Meissen, in Germany. France followed with Sevres in 1756.

In 1774 the French chemist Duchateau conceived the idea of making porcelain teeth after he had seen the dentists of those days using carved ivory, ox bone, and hippopotamus tusk to replace missing human teeth. Because of financial difficulties Duchateau failed to accomplish his goal.

The making of the first porcelain teeth is credited instead to his contemporary, Dr. Du Bois de Chement, who succeeded in producing such teeth after years of effort. After his initial invention, he spent most of his remaining life doing research work in dental porcelains. He introduced pigments in porcelain teeth to match natural teeth, and investigated ways and means of producing a complete denture in porcelain. This latter project was not accomplished during his lifetime. Lee says that undoubtedly Duchateau and de Chement obtained their ideas, and some knowledge of manufacturing porcelain ware, from Sevres and other porcelain manufacturing concerns.

In 1808 an Italian dentist, Dr. Guiseppangelo Fonzi, invented a porcelain tooth with an anchorage so that the tooth could be fastened into a base. He made the first "terra-metallic" teeth, which were furnished with small platinum hooks for retention.

Another French dentist A.A. Plauteau, came to America in 1817 with porcelain teeth made in France. For three years he made porcelain teeth for use in his own practice. However, porcelain teeth were not available to dentists in the United States until Samuel S. Stockton produced the first commercial teeth in 1825.

Clark (127) writes that prior to 1838, dental porcelain was an opaque white material resembling that used in industrial ceramics. In 1838 Elias Wildman formulated a translucent porcelain which he was able to produce in colours, similar to those of natural teeth. Artificial teeth, then known as mineral teeth, were made from this new material.

In 1844 Dr. Samuel S. White, S.S. Stockton's nephew, used feldspar obtained in Chester County, Pa., to produce artificial teeth with further improved translucency.

For about forty years following White's work, the use of dental porcelain was confined almost exclusively to the field of artificial dentures. Efforts were made to utilise this material for restorative procedures, but these were largely unsuccessful until C.H. Land conceived the principle of using platinum foil, sheet, and tube as a matrix material for crowns and inlays.

There is some doubt as to the year Land developed the technique. In 1889 Land (2) reported on five years' experience in fusing porcelain for inlays and crowns, which would make their origin 1884. Oppice (44) refers to the advent of the Land crown as 1895, but the literature does not support this view. W.L. Fickes (44), and Argue (24) agree on the year 1886 as the advent of Land's platino-porcelain crown, and 1902 as the year Land developed the all-porcelain jacket crown.

Land (10) himself stated in 1903 that other workers had antedated him regarding the porcelain jacket crown, but did not mention them by name. He said "Porcelain as applied in dentistry prior to 1885 was exclusively confined to the manufacture of artificial teeth and a few cavity stoppers. The dawn of the new era, which revealed a field of greater scope and increased value, was first made known to the profession by the publication of an article in the Independent Practitioner* of August 1886 entitled 'A new system of restoring badly decayed teeth". Following this, another article appeared in the February 1887 number of the same journal entitled "Metallic enamel sections : a new

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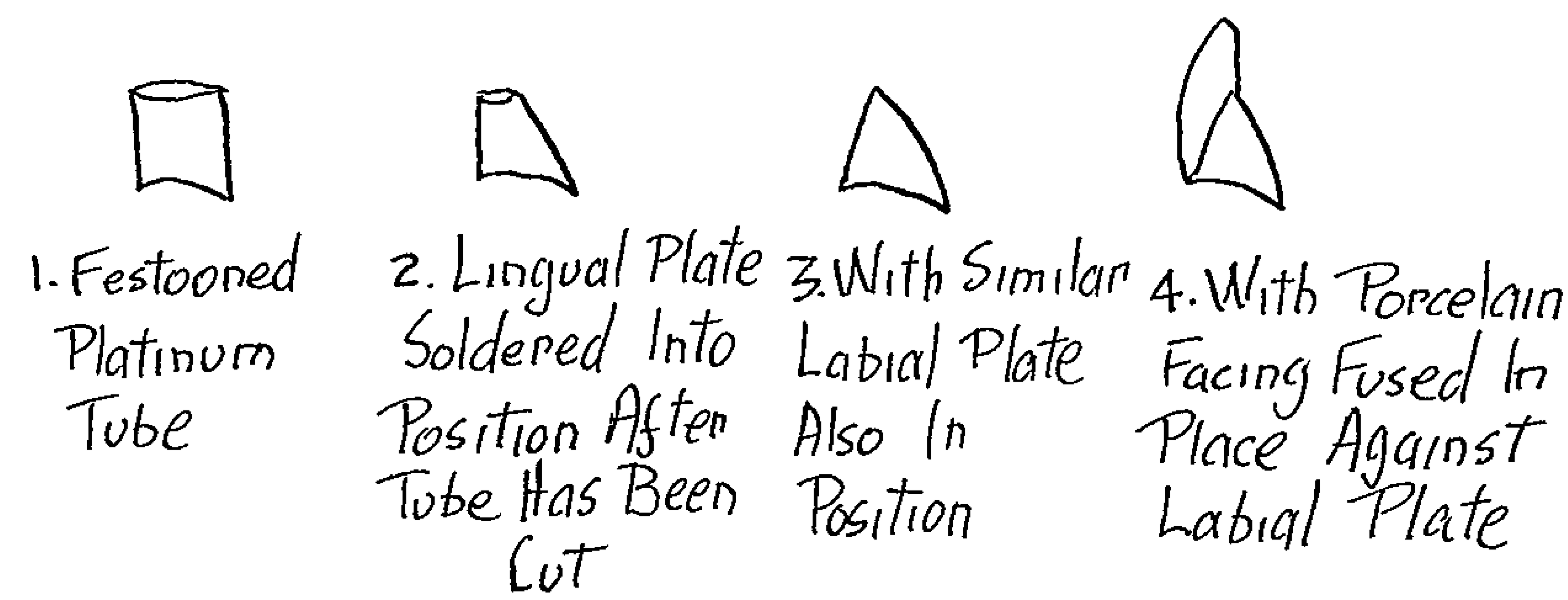
* This journal not available in Sydney.

system for filling teeth." In addition, an original paper entitled "Metallic enamel coatings and fillings" appeared in the August 1887 issue of the same journal. All three articles were profusely illustrated and combined, they gave a very elaborate description, showing various forms of porcelain contours, fillings, crowns, and enamel caps - or jacket crowns."

It would seem reasonable to assume that Land developed the first practical porcelain jacket crowns and that he evolved two types. The first, developed about 1886, consisted of a shell crown soldered together from platinum or iridioplatinum tube and sheet of 30 gauge (B.& S.). A porcelain slip facing, ground from a denture tooth, was joined to the labial surface of this metal crown with dental porcelain of a lower fusing point than the facing. The lingual surface of the metal crown was not covered with porcelain, and the tooth preparation was minimal, without a shoulder, and with very little lingual reduction. This type of preparation was simple to carry out, and its shape tended to simplify fabrication of the metal part of the crown. Modern thought would tend to classify this crown as a metal veneer crown with a fused porcelain facing, rather than as a porcelain jacket crown.

Capon (9) in 1902 described in detail the stages in building up this type of Land porcelain jacket crown.

TYPICAL LAND PORCELAIN
JACKET CROWN



In 1891 Capon (3) reported on the restoration of six eroded upper anterior teeth for a patient utilising the type of crown just described. The metal coping was formed and shaped on the tooth, then soldered, and the porcelain was fired in a small gas furnace.

In 1891 Hunt (4) described a similar technique for fabricating a porcelain jacket crown, and stated that by forming a floor inside the band to fit the prepared face of the root, this type of crown could also be utilised for pulpless teeth.

In 1900 Ernsmere (6) described his technique utilising the Land porcelain jacket crown. He adapted a matrix from 40 gauge (B.& S.) platinum and soldered the joint with pure gold. He suggested that the platinum be made wrinkled or rough where it contacted the porcelain. A thin layer of porcelain was fused against the platinum and a Land porcelain veneer of the correct shade and size adapted. The space was filled in with porcelain and again fired.

Most of the papers published at this period were notable for their lack of detail regarding the actual construction of the crown. There was also a distinct tendency to omit any reports of failure of these crowns. One would expect failure due to fracture to have been fairly frequent, as the fabricated metal coping lacked rigidity, and as the porcelain was only fused against the labial surface of the metal, the bond between the two must have been relatively weak.

About 1902 Land (10) developed his second type of porcelain jacket crown. In this paper he suggested the use of a shoulder in preparing a vital tooth for a jacket crown, and also the use of a matrix of platinum foil (in contra-distinction to the previous use of tube and sheet of 30-40 gauge B.& S.) over which porcelain was fused. As previously, a slip porcelain facing was used but this time the whole surface of the matrix was covered with porcelain, and the platinum matrix was stripped from the inside of the crown prior to its cementation - a major step forward in aesthetics. A high fusing porcelain was used for the first firing over the matrix, and a porcelain of lower fusing point was used to unite the slip facing with this first bake, and build the crown up to full contour.

In 1904 Spalding (11) developed this type of porcelain jacket crown still further. He removed all the natural enamel of the tooth to slightly below the gingival margin leaving a shoulder. Over this he adapted a matrix of 0.001 inch platinum foil. Spalding stated that there were two ways of building up the porcelain on the matrix. Firstly, by building up and carving entirely with the porcelain body, and secondly by using a facing ground from a porcelain denture tooth, and baking this to the matrix with body which supplied the balance of the coating. He advocated the former method for premolars and molars, presumably because aesthetics were not quite so important in this region. The latter method he preferred for anterior teeth, as better colour control was possible using the stock facing.

Goslee (12) criticised the porcelain jacket crown in 1903. He said "The advocates of this style of construction claim that it is more or less universally indicated in restoring the crowns of the six anterior teeth, upper and lower, and that the principal advantage lies in the conservation of tooth structure and the preservation of the pulp. While both of these considerations are always of material significance to the conscientious operator, and should be observed whenever possible, still they do not constitute the complete maximum of requirements of crown construction and application when combined with the highest aesthetic possibilities, because the requirement of strength is of equal importance, having so great an influence on the serviceability and permanency of the work."

Goslee considered that many failures in porcelain jacket crowns by fracture were brought about by the porcelain being too thin, and this part of his criticism was no doubt true in many cases. It is a rather sad commentary on things at that time that the possibility of failures was not even mentioned by leading clinicians, such as Land and Spalding, in their writing. Goslee also considered (no doubt rightly) that in many cases porcelain jacket crowns were too bulky and shapeless in appearance. For general use he preferred one of the contemporary post crowns, such as Logan or Richmond, even though such use entailed removal of the pulp of the tooth. However such criticism as Goslee's did not appear to slow further development of the porcelain jacket crown.

Until about 1908 fabrication of the porcelain jacket crown was done by the direct method i.e. the platinum matrix was adapted on the patient's tooth. Usually a soldered joint was employed. Successive bakes of porcelain were made and the crown tried back on the tooth between bakes to check fit and contour.

In 1908 Baldwin (14) advocated constructing the porcelain jacket crown without the use of a stock facing, over a platinum matrix which was adapted on a copper amalgam or cement die. This was the first mention I found in the literature of adapting the matrix on a die. The matrix was then returned to the tooth and the porcelain added in from two to four bakes to check on its contour. This might be termed an indirect-direct technique.

In 1909 Riethmueller (15) developed a direct-indirect technique. He fabricated the platinum matrix on the tooth and then soldered the seams. The matrix was then replaced on the tooth and an overall plaster impression taken. The inside of the plaster impression was painted with a separating varnish and a model poured with ceramic inlay investment. This model, incorporating the platinum matrix, was utilized to build up the porcelain crown. The section of the model containing the crown was sawed from the rest and the porcelain fired in a furnace equipped with a pyrometer. Riethmueller demonstrated by means of photographs and case histories that the porcelain jacket crown was a practical restoration with a wide range of application.

Frank (16) also in 1909, presented the more commonly used technique. Following the tooth preparation, a compound impression was taken inside a copper or German silver shell, correctly festooned. A wax impression of the arch and a wax "squash bite" were also taken. The die was made with cement and seated in the wax impression, which was then poured, resulting in a working model with a removable die. This was then articulated against a model of the opposing teeth by means of the wax bite registration. This was the first description of the fully indirect technique I was able to find in the literature.

In Frank's experience the high fusing porcelains then available were superior to the low fusing variety. These high fusing porcelains fused around 2550°F, which is higher than the fusing point of most high fusing porcelains in use today. This preference for high fusing porcelains was common among the prominent porcelain workers of the period, and at that time there may have been some justification for it. Low and medium fusing porcelains were held to be inferior materials by these clinicians, and were often rather derisively referred to as "glass". However these opinions were founded only on empiricism, as no scientific evaluation of these materials had been published up to that time. This irrational preference for high fusing porcelains (one might almost say they had "snob appeal") has persisted in the minds of many men almost up to the present day.

Schneider (17) in 1909 advocated the use of the "Steele's self-locking matrix" or tinner's joint matrix. He also advocated firing the whole crown in one bake, using two colours of porcelain. He considered that when properly manipulated, one baking was all that was required, there being almost no shrinkage and no pulling of the matrix from the gingival shoulder (a pious, but forlorn hope!). He did not suggest a try in of the crown before cementation.

Straussberg (23) in 1911 advocated ditching the porcelain down to the platinum matrix, about 1 mm. from the shoulder, before firing the first bake, in order to allow shrinkage of the porcelain to take place without distorting the platinum matrix in the vital shoulder region. He also stated that during bisque firing, it was safe to remove the crown from the furnace while it was still hot, but not safe when it had been glaze fired. In the latter case he stated that it must be left in the furnace until cool enough to be handled in the fingers. Apparently the need for annealing the porcelain after its final bake to resolve any residual stresses was well understood at this time. The platinum was then peeled out and Straussberg advocated that the inner surface of the porcelain crown be etched with hydrofluoric acid prior to cementation.

He preferred to build up the crown entirely from porcelain powders and claimed that adapting slip facings was time consuming and also that the facing must be ground so thin that all the yellow body colour was removed. Thus it became necessary to substitute for this missing colour a yellow cement which he claimed lead to a poor aesthetic result.

Straussberg argued that a facing was weakened by the fusing required to build it into a crown (i.e. it became overfired) and also the union between facing and porcelain was, at best, not as strong as a crown fused to a gloss at once in a single mass. In fact, few jacket crowns of any sort can be fused in less than two bakes.

In the discussion following presentation of this paper, W.H.Pruden questioned whether the prepared tooth, having had its enamel removed, would have sufficient strength, and he considered that it would be more desirable to remove the pulp and construct a post crown. Conservation of healthy pulps did not appear to be regarded with the same importance as it is these days.

Others questioned whether the all porcelain jacket crown was sufficiently strong for "close bite cases". In reply, Straussberg stated that, in his opinion, the all porcelain jacket crown was not suitable for close bite cases. (Presumably in such cases he resorted to pulp removal and the use of a post crown). Hane suggested that the cement used in setting the crown would subsequently cause pulp necrosis after a period of time. This last criticism may be justified if an over-thin mix of cement is used (with resultant free acid) on a preparation which is relatively absorbent due to not having been treated with a varnish or other protective liquid.

In 1912 Hawkes (19) demonstrated the possibilities of using porcelain jacket crowns for restoring the anterior teeth as part of occlusal rehabilitation, in this case increasing the patient's vertical dimension of occlusion.

In 1912 Coston (20) advocated the use of silicate cement set under pressure for the formation of dies for porcelain jacket crown construction. He considered that such dies would withstand both burnishing and swaging of the platinum foil matrix.

As late as 1914 Villain (30) was still advising the use of gutta percha for setting crowns, but at this time most of the profession was using zinc phosphate cement.

In 1915 Custer (22) advocated cementing porcelain jacket crowns with silicate cement. He rightly claimed that silicate cement was more translucent than zinc phosphate cement, but his claim that it resisted chemical action in gingival areas better than zinc phosphate cement, is still not proven.

Argue (24) in 1916 spoke in favour of the porcelain jacket crown restoration. He mentioned the desirability of conserving and maintaining a healthy pulp, and the fact that porcelain is a good thermal insulator. He also referred to the use of porcelain jacket crowns to remedy malaligned teeth. He suggested that insufficiently accurate adaptation of the platinum matrix could result in a poor fit of the finished crown with consequent need for excess cement, which subsequently leached out, leaving a space for the proliferation of bacteria.

In 1918 Lewis (25) condemned intentional removal of healthy pulps in order to construct post crowns, and entered a plea for the wider use of the porcelain jacket crown by the profession. His technique made use of articulated models with a removable amalgam die. He considered that the restoration could be completed in two appointments, without a try-in stage.

Buell (26) in 1920 considered that the porcelain jacket crown surpassed all others, as it placed at the cervical region of the tooth a material which is received very kindly by the tissues, could be made so as to conform perfectly to the anatomy of the tooth, and placed between the pulp and all external influences a nonconducting material, which protected it from all thermal shocks. He stated that the possibilities of imitating form and colour under all circumstances were limited only by the skill of the operator. Buell also suggested the use of a cast core for pulpless teeth, made from pure silver or 22 carat gold alloy, anchored by one or two posts, as the case might require. For applying the porcelain to the matrix, he employed the use of a paper tube wrapped around the die, which was intended to produce better condensation of the porcelain.

Hovestadt (27) produced an excellent paper in 1919 dealing with the fundamental issues of the porcelain jacket crown technique. He laid stress on tooth anatomy and histology, and their influence on proper tooth preparation.

He said "The cardinal principle of the porcelain jacket crown is the exact reproduction of the natural tooth in shape and colour. The second principle is the protection of the pulp and peridental membrane from injury. The third principle is the protection of the soft tissues so that their functions will continue normally after restoration by the crown. The fourth principle is the correct restoration of all anatomical details by the porcelain jacket crown, such as cervical contour, correct contact points, occlusion, and articulation".

He also said that there is no material that is so favorably received by the gum tissue as is porcelain. According to the work of Allison (274), Pini (275), and others, this latter statement still holds true. Hovestadt also recognised the need for proper diagnosis before undertaking the restoration of a tooth by means of a porcelain jacket crown, and he considered the use of radiographs to be a considerable aid in this respect.

The use of varnish to protect the exposed dentine of the prepared tooth was also advocated by Hovestadt, who as well made use of temporary treatment crowns of white gutta percha, or celluloid crown forms filled with gutta percha or cement.

In 1920 Chayes (61) criticised the widespread use of porcelain jacket crowns on vital teeth, as he considered the restoration "was harmful and unsafe because it robbed that part of the tooth which was left above the gum of its bath in the sea of air which surrounded it". Such a criticism seems to be something of an anachronism, and the subsequent pulp deaths under porcelain jacket crowns that Chayes observed were probably due to incorrect tooth preparation and protection.

During this period tooth preparation techniques did not change greatly. There was a trend away from the removal of labial and lingual enamel by means of chisels and cleavers, and these were replaced by the use of stones. It was recognised quite early that the frictional heat developed was a definite danger to the health of the pulp, and a stream of water, usually directed by an assistant, was employed to cool the cutting instrument and the tooth.

Megaw (33) in 1921 described a technique for tooth preparation which was very similar to that used up until recent years before the advent of ultra high speed water-cooled cutting instruments. He also advocated obtaining gingival retraction by the use of gutta percha temporary crowns. The need for placement of the shoulder slightly below the free margin of the gingiva was well recognised at this time.

Scherer (29) in 1922 emphasised the importance of establishing and maintaining the health of the gingival tissues and supporting structures of teeth involved in crown and bridgework.

Parfitt (31) in 1923 utilised Buell's (26) technique of forming a paper tube around the die in which to condense the porcelain. He also suggested that the final glazing of the finished crown be accomplished by using porcelain with a lower fusing point than that used to build up the bulk of the restoration.

Vehe (28) in 1923 drew attention to the importance of proper occlusion in porcelain jacket crown construction. He stated "The one condition that the operator must bear in mind always is that of a perfectly balanced articulation with the restoration and the immediate area at least. This is a supremely important requirement for all restorations in porcelain, whether an inlay or a crown, and not only must this requirement be complied with before the patient is dismissed, but the occlusion, not only in centric but in eccentric, should be inspected at intervals and corrected if necessary".

By the end of 1923 the porcelain jacket crown had firmly established itself in the field of operative dentistry. Its aesthetic, biological, and functional attributes were well understood, and fairly dependable methods for producing it had been evolved. Since that time refinements and improvements have been made, mainly in materials, and these improvements have lead to some detail variation in techniques, but the basic conception of the porcelain jacket crown has remained unaltered, and its longevity is a tribute to the work of men like C. H. Land.

PORCELAIN AS A MATERIAL

Composition and Manufacture

A good deal of information is available regarding the composition and manufacture of porcelains used in other fields, but the information regarding dental porcelain is scant in size and unreliable in nature. Peyton, et al (235) wrote "Despite its relatively long history, little has been published of a scientific nature on the subject of dental porcelain. This has been due in part to the desire by the manufacturers of these materials, to keep the nature of their products from one another, and to the fact that the practice of forming all porcelain objects is more of an art than a science".

Le Gro (51) wrote much the same thing in 1925, and the attitude of dental porcelain manufacturers does not seem to have changed appreciably since. Requests for details regarding the composition and manufacture of dental porcelains have met with replies of such a general nature as to be almost useless. As a thorough knowledge of these materials exists only within the laboratories of the manufacturers, it is very difficult for outside workers, such as in the research departments of the dental schools, to make any worthwhile contribution to the further development of the material. The result has been a painfully slow evolution towards better dental porcelains.

Megaw (245) stated that in the ceramic industry dental porcelains are not classed as true porcelain, but as porcelain glaze. To secure the depth of translucency needed to simulate natural teeth, dental porcelain is made with glazing qualities.

Hodson (204) attempted to analyse the finished products but has been only partly successful, as they are extremely complex in nature. She stated that a preliminary study of 15 porcelain powders used in the School of Dentistry, University of Washington, made by examining the powders microscopically, and by X-ray diffraction, revealed the powders to be composed of feldspar, quartz, and glass. Particles of feldspar and colouring minerals were present as enclosures in glass fragments. Some of the high fusing porcelains were a feldspar-quartz mixture, but all the others were partially melted frits. Hodson says that the use of frit as the only body constituent of dental porcelain is an unusual ceramic practice, and is dictated by the characteristics required of a dental porcelain.

In another paper Hodson (199) stated that a frit is a glass that has been melted, quenched, and ground to the desired fineness. The fritted dental porcelain powders which contained minerals suggested that the fritting process was not carried to a completely glassy state before quenching. The use of a frit body offers the following advantages in dentistry:-

(1) Melting temperatures are standardised and controlled by the formulation of the frit glass.

(2) Firing schedules are shortened because the majority of thermal reactions occur in the preparation of the frit, and dental firing consists primarily of re-fusing the glass particles.

(3) The absence of hydrous minerals such as kaolin reduces drying shrinkage and shortens drying time.

There are also disadvantages in using this type of porcelain.

(1) The frits are difficult to form.

(2) There is no dry strength.

Semmelman (249) said that it is normally more convenient to quench immediately after fritting, as it reduces the amount of grinding required. However, he says he is confident that some porcelains are made without quenching and that this does not substantially alter the pyrochemical reactions which take place. He says that there is no standard fritting procedure, and it is quite possible that some materials will be fritted more than once. The fritted powders are silk screened, although there is no consistency as to the exact sizes. In general, vacuum firing has resulted in a trend towards finer particles. Lee (267) draws attention to the importance of particle size. He says the proportion of different particle sizes in the powder is very important because it controls the working properties of the porcelain. If the particle sizes are all alike, either fine or coarse, the particles will not interlock and pack solidly when gentle vibration is applied in building up the jacket crown on a matrix.

Most leading dental porcelain manufacturers such as the Dentists' Supply Co., the Vita Company, and the Columbus Dental Mfg.Co. state that they do not use organic or other binders in their jacket porcelains because they tend to increase the shrinkage rate, and are not really necessary if the porcelain has been manufactured correctly.

Hodson (204) confirms the absence of clay or kaolin in the powders through X-ray diffraction analysis, but some crystalline silica was detected. The large amount of glass in these dental porcelains suggests that they would have lower resistance to the forces of mastication than would characterise more crystalline porcelains. When the properties of ceramic materials are considered together with the requirements of dental restorations, the use of a crystalline rather than a glass body is indicated. However such bodies are opaque and bear little resemblance to the appearance of natural enamel.

Semmelman (249) says that dental porcelains differ greatly in their composition and process of manufacture. He gives the approximate compositions of most dental porcelains as falling within the range of:-

75 - 100%	feldspar
0 - 25%	silica
0 - 1%	kaolin

As well, the porcelains may contain additional fluxes, pigments, and opacifying agents. Considerably more information is known concerning the raw materials used in dental porcelain manufacture and these will now be considered.

RAW MATERIALS USED IN MANUFACTURE

Feldspar and Nepheline Syenite

These are both minerals from the same family and one or other, or a mixture of both, forms the main constituent of dental porcelain.

Salmang (268) sounds a warning note when he says "Knowledge of the chemical composition of the feldspars does not enable us to say anything about their microscopic structure and very little about their sintering and melting behaviour".

Lee (266) states that the principal components of natural feldspars are:

soda feldspar	($Na_2O \cdot Al_2O_3 \cdot 6SiO_2$ or $NaAlSi_3O_8$)
potash feldspar	($K_2O \cdot Al_2O_3 \cdot 6SiO_2$ or $KAlSi_3O_8$)
lime feldspar	($CaO \cdot Al_2O_3 \cdot 2SiO_2$ or $CaAl_2Si_2O_8$)

Hughes (114) states that feldspar occurs crystallised in rhombic prisms and is fairly widely distributed over the earth's surface in many forms, but only those free from soda and lime are used in the manufacture of dental porcelain. The mineral is yellowish pink in its natural state, but is translucent and colorless when fused, and contains numerous small opacifying crystals and air bubbles.

Lee (267) says the commercial feldspars prepared at the mines for use in the pottery and glass industries are not used for dental porcelain. Only the purest and highest quality <u>potash feldspar</u> is specially selected at the mine and set aside for dental porcelain. The pieces of feldspar are first carefully sorted by hand to eliminate obvious impurities and are then run through a jaw and roller crusher. This crushed material is put through a magnetic separator to eliminate all of the iron particles picked up from the crushers and rollers, and it is then ground wet in pebble mills to pass through a 150 mesh sieve. It is dried and screened again through silk cloth for further particle sizing and is now ready for use in the composition of dental porcelain.

Skinner and Phillips (251) state that when feldspar is fused it does not exhibit a sharp melting point, but rather gradually begins to melt at approximately 2000°F (1100°C), and at 2370°F (1300°C) becomes a liquid with a viscosity approximately 10^6 times that of fused glass, according to Hodson (199).

Le Gro (51) says that with fluxing agents such as sodium carbonate (NA_2CO_3), sodium borate ($Na_2B_4O_7$), or potassium carbonate (K_2CO_3) its fusing point becomes lower according to the quantity and nature of the fluxing agents. Feldspar so treated acts as a binder by turning practically to a glass. Le Gro (51) says that under the microscope an ordinary fused piece of porcelain shows that the feldspar attacks the granules of quartz, and when subjected to a higher temperature, seems to cause the quartz to go into solution.

Lee (266) gives the following approximate composition for nepheline syenite:-

50%	soda feldspar	($Na_2O \cdot Al_2O_3 \cdot 6SiO_2$ or $NaAlSi_3O_8$)
25%	potash "	($K_2O \cdot Al_2O_3 \cdot 6SiO_2$ or $KAlSi_3O_8$)
25%	nephelite	($Na_2O \cdot Al_2O_3 \cdot 2SiO_2$ or $Na_2Al_2Si_2O_8$)

He says nepheline syenite has a much longer sintering range than either feldspar or mixtures of the feldspars. This provides for the long firing range observed when nepheline syenite is the principal flux in the body. Another advantage of the nepheline syenite is that the thermal expansion of the crystalline (anisotropic) and glass (isotropic) states is fairly similar, so that this property is not strongly dependent upon the relative amounts of the two phases present. Since maturation of the body involves arrested reactions, variations in the degree of firing will not result in as large a variation in thermal expansion as with feldspar. Dental porcelain may be almost all feldspar or nepheline syenite says Lee. As newer dental porcelains seem more resistant to sudden temperature changes, I would suspect that perhaps nepheline syenite has been largely substituted for the feldspar.

Kaolin

Hughes (114) states that the name kaolin is derived from a Chinese word Kauling, meaning a high ridge, and is the name of a high ridge near Jachau Fu from which a great deal of this material is, or was, obtained.

Peyton et al (235) state that kaolin is produced in nature by the weathering of feldspar, during which the soluble potassium silicate is washed out by acid waters.

Hughes (114) says that kaolin is a fine white clay, a variety of aluminium silicate, and is formed due to the weathering of feldspathic and granite rocks. These rocks, being granular in structure, take up water and when this freezes the outer surfaces of the rocks split off and are carried away on thawing, and by the action of rain, settle in beds. A large deposit of the material also exists in Germany.

Lee (266) gives the following table showing the approximate chemical constitution of two important kaolins (percentages).

	Kaolin 1	Kaolin 2
Alumina Al_2O_3	37.41	39.18
Silica SiO_2	45.52	44.36
Iron Fe_2O_3	1.68	0.42
Titania TiO_2	1.30	1.33
Calcia CaO	0.004	0.005
Magnesia MgO	0.03	0.02
Manganese oxide MnO	0.0005	0.005
Potassia K_2O	0.005	0.002
Soda Na_2O	0.011	0.01
Sulphur trioxide SO_3	0.13	0.08
Phosphorus pentoxide P_2O_5	0.08	0.10
Water H_2O	13.93	14.09

Le Gro (51) states that kaolin is valued as an ingredient of dental porcelain because it imparts stability of form, thus facilitating the moulding and carving. This quality he says is due to the dispersed nature of fine clay particles which have the properties of a suspension colloid. Brecker (149) states that kaolin contributes toughness to the fired porcelain but this is debatable. It does increase both the opacity and the shrinkage of the porcelain on firing, and with the advent of finer porcelain powders now available due to development of the vacuum firing process, the use of a binder no longer appears necessary.

Semmelman (249) says that it forms no more than 1% of most dental porcelains and McBean (43) says that as it tends to produce opacity in the fired porcelain, and possibly added shrinkage, it appears to have been omitted from most modern dental porcelains. The work of Hodson (204) adds support to this view.

Silica SiO_2

Lee's treatise on ceramics (266) covers the subject of the use of silica in dental porcelains very well, and the following is taken from it.

Types of Silica found in Nature

(1) Rock type known as quartz stone. It occurs commonly throughout the world, but is not commonly used in the

ceramic industry, principally since it contains impurities.

(2) Granular type commonly known as silica sand. It is found in practically all locations on the earth, particularly on ocean beaches and in the mountains. It is found sufficiently pure so that it can be used in the ceramic industry without beneficiation.

(3) Powder type, an amorphous silica known as diatomaceous earth or diatomite. It rarely occurs in pure form, since it contains other minerals or impurities, thus it is not used in classic ceramic bodies. Its principal use is in the manufacture of thermal insulation.

Various Forms of Silica

Lee states that silica exists in a great variety of forms. The three principal crystalline forms are quartz, tridymite, and cristobalite. Quartz is the form that is stable under atmospheric pressure at all temperatures up to 870°C. Tridymite is the stable form from 870-1470°C. Cristobalite is stable from 1470°C to its melting point at 1728°C. The transformation of silica from one of these forms to another is sluggish. Each of the three principal crystalline forms of silica exists in more than one modification, depending upon the temperature. The inversions occur almost instantaneously when the inversion temperature is attained. The alpha-beta, or high-low inversion of quartz occurs at 573°C. This has important practical significance since the rapid volume change can result in cracking of ware containing large amounts of free quartz, especially when such ware is cooled rapidly past this inversion temperature. Also the inversion of beta quartz to tridymite at 870°C involves a volume change which has practical significance. Tridymite has two inversions at 117°C and 163°C. Tridymite has an unstable structure and is rarely found in nature. The alpha form changes to the beta form at the inversion temperatures, but below 870°C tridymite is very unstable. From 870°C to 1470°C it is stable beta tridymite. Above this temperature it becomes alpha cristobalite.

Cristobalite is peculiar in that its high-low inversion point changes through a range of temperature according to the previous history of the material. Cristobalite is stable from 1470°C to 1728°C but above this temperature melting starts. These three crystalline forms of silica may exist in intimate mixtures for a long time, even though they are not in equilibrium and change form with temperature changes. A low temperature tridymite and cristobalite may exist for an indefinite period. However, alpha quartz is the only stable form of silica at these low temperatures. All forms of silica when heated to sufficiently high temperature fuse and form amorphous silica glass.

Brecker (149) says that silica is insoluble in water and in all acids except hydrofluoric acid. It can be dissolved in alkalis or in a boiling solution of sodium bicarbonate.

Le Gro (51), Peyton et al (235), and Brecker (149) state that the finely ground silica present in dental porcelain remains unchanged in the temperature range required to fuse dental porcelains and that it acts as a refractory skeleton maintaining the form of the porcelain during firing. To quote Le Gro (51) "Its high fusing quality and ability to withstand the fluxing elements in feldspar make it a valuable ingredient, and allow it to act as a filler and impart great strength structurally to the fired mass".

More recent literature (266) on the subject leads one to suspect that silica is more chemically active in porcelain at elevated temperatures than was formerly thought.

Fluxes

Brecker (259) states that the flux is the lowest melting constituent and its composition depends upon the desired firing temperature of the porcelain. When it melts it reacts with other constituents to produce the final glass-like form.

Lee (267) says that borax, boric acid, sodium carbonate, fluorspar, lithium carbonate, and zinc oxide are used as fluxes (but are not the only ones).

Semmelman (249) states that each of the fluxes has its own characteristic advantages and disadvantages. Many induce undesirable opacity, and others may affect the firing characteristics of the porcelain undesirably. Conventional glass fluxes such as lead are avoided because they are very slightly soluble in the mouth. He further states that the Dentists' Supply Company does not add any additional fluxes to its porcelain after fritting, and he doubts if any other manufacturer would do so.

Pigments and Opacifiers

Semmelman (249) states that the pigments commonly used for dental porcelain are normally metal oxides which have relatively high resistance to temperature. Many of the conventional ceramic pigments do not have sufficient heat resistance to withstand the normal firing temperatures of dental porcelain, and certain pigments are also contra indicated for optimum colour development in vacuum firing.

Hughes (114) lists some of the metals and metallic oxides commonly used as pigments in dental porcelain:-

Material	Colour Effect Produced
Gold Au	rose red
Gold Peroxide AU_2O_3	bright rose red
Purple of Cassius $SnO_2 + Au$	purplish red
Sponge platinum or filings Pt	greyish blue
Cobalt Oxide Co_2O_3	blue
Uranium Oxide $UO_2 - 2UO_3$	orange yellow
Silver Oxide $A_{g_2}O$	lemon yellow
Zinc Oxide ZnO	lemon yellow
Titanium Oxide TiO_2	bright yellow

Lee (267) lists materials used to develop opacity (opacifiers) as including aluminium oxide, tin oxide and zirconium oxide. Brecker (259) states that some of the pigments used are responsible for the newer dental porcelains imitating the fluorescence of natural teeth, but there appears to be no literature available dealing with this aspect of dental porcelain.

CLASSIFICATION OF DENTAL PORCELAIN

By far the greatest volume of dental porcelain manufactured is used in the production of artificial teeth, and it is probable that most of the research carried out by manufacturers is directed to this end. However, as it is probable that the porcelain used for artificial teeth resembles fairly closely that used for jacket crowns and inlays, it is quite likely that the latter type has benefited indirectly from the results of this research.

Dental porcelain intended for jacket crowns and inlays is classified firstly as to its fusing temperature and secondly as to whether it is primarily intended for air or vacuum firing.

In the early days of dental porcelain the materials were apparently not fritted, and hence had a tendency to have very high fusing temperatures in the range 2350-2550°F. Porcelains with lower fusing temperatures were developed from these by the addition of fluxes, still apparently without fritting. These porcelains were not always reliable, especially as some of the fluxes used were slightly soluble in the mouth, even after the porcelain had been glaze fired. As a result the leading clinicians of the day developed a prejudice against all porcelains with low fusing points. With the advent of the fritting process it became possible to produce dental porcelains with much lower fusing points (for example, Apco 1875°F) which contained no free flux or binder, and which had physical properties at least equal to the high fusing varieties.

Prejudice dies hard however, and it has only been in recent years with the publication of detailed comparisons of the physical properties of various dental porcelains that the myth has been finally exploded.

Lee (267) states that in the vitrification range of ceramic products dental porcelain occupies a midpoint between a true porcelain and a glass.

Megaw (245) and Johnson, Phillips, and Dykema (264) classify dental porcelain as high or low fusing according to whether it fuses above or below the melting point of pure gold 1945°F (1060°C).

Peyton et al (235) give the following temperature classification:

low fusing	1600 - 1950°F
medium fusing	2000 - 2300°F
high fusing	2400 - 2500°F

Lee's (267) classification differs slightly -

low fusing	1600 - 1800°F
medium fusing	2000 - 2200°F
high fusing	2300 - 2400°F

These conflicting temperature classifications obviously lead to confusion, and are of little use in any case. The important thing is not whether a given dental porcelain is designated as high, medium, or low fusing by this or that authority. It is the fusing temperature of the material as supplied by the manufacturer which is of primary interest, as this is the starting point for the development of a suitable firing schedule.

The current trend is away from jacket crown and inlay porcelains having very high fusing points. This I suspect is mainly a matter of economics. Porcelain furnaces used for the fabrication of jacket crowns and inlays from porcelains fusing in the 2300-2500°F range are normally equipped with platinum wound muffles, which are a very costly item. If the porcelain has a fusing point below 2150°F it can be fired in a muffle wound with a base metal alloy (nickel-chromium or similar) costing approximately 1/20th as much as a platinum wound muffle. Two of the most recently introduced materials, both intended for vacuum firing, Vita 2066°F, and Dentsply 2100°F, fall into this category.

MANIPULATION AND CONDENSATION OF PORCELAIN

Dental porcelain is supplied as a dry powder. It is mixed with water to form a paste and moulded over a platinum matrix to form the crown, which is then fired in a furnace.

Le Gro (53), Cohen (157), and all other writers agree that cleanliness is of the utmost importance in handling porcelain, at least until it has been glazed. Some impurities will burn out during the firing process, but others do not and may be visible as discolorations when the crown has been glazed. Others may liberate gas bubbles in the porcelain during firing which may weaken it, as well as spoiling the appearance of the restoration. Le Gro (53) warns that perspiration from the fingers often contaminates partially fired porcelain in a manner that sometimes cannot be detected until the final glaze, leaving an unclean smudge fused in the work.

Water is used as the medium or vehicle for the porcelain powder. Clark (92) and Klaffenbach (133) agree that it is a most suitable medium because of its low viscosity and extremely high surface tension. Clark compares its efficiency in this regard with alcohol.

	Specific Gravity	Surface Tension
alcohol	0.79	24.5 dyne/cm.
water	1.00	73.5 dyne/cm.

As the specific gravity of porcelain powder is approximately 2.4, it will obviously be easier to condense by gravitation alone in alcohol. However techniques employing gravitation alone require that the porcelain be confined in some type of rigid mould so that it does not have to be built up beyond the walls of the mould. Gill (139) in 1946 employed such a moulding technique but was the only one I could discover who did so. Other writers claimed to do so, but in their techniques part of the crown extended beyond the confines of the mould, hence gravitation was not the only method of condensation utilised.

Most forming techniques utilise only a partial mould or base above which the porcelain mix is piled, condensed, and shaped. The influence of surface tension is one of the chief factors in condensation for such techniques, and hence water is the more suitable medium.

Radermacher (273) states that in most areas tap water is quite suitable, but I consider that for the trifling cost involved, it is better to be on the safe side and use distilled water. Tap water may contain particles of rust etc. from the pipes, and these impurities can have two deleterious effects - firstly they may discolour or form gas bubbles in the porcelain, and secondly they may reduce the surface tension of the water, making it a less effective vehicle for condensation of the porcelain.

The porcelain powder may be mixed with water either on a glass slab or in a shallow receptacle, such as a dappen dish, watch glass, or small porcelain dish. Le Gro (53), Doner (120), Johnson, Phillips, and Dykema (264), and Radermacher (273) all favour the use of a glass slab. They caution against vigorous spatulation with a metal spatula, as the abrasive action of the porcelain particles is capable of incorporating metal particles from the spatula. Doner advocates the use of a bone spatula, presumably expecting that any particles of bone incorporated would be burnt out in the furnace. Radermacher prefers a glass spatula, as any particles of glass incorporated will become an integral part of the porcelain without having any adverse effect. The use of a glass slab for mixing the porcelain possesses two disadvantages - Firstly if vibration of the slab is carried out to eliminate entrapped air, the mix will run all over the slab, and secondly, a greater surface area of porcelain is exposed on a slab, and consequently evaporation of the water in the mix will be more rapid.

It is more convenient to mix the porcelain under vibration in a small shallow receptacle with a glass spatula. The receptacle can be covered when not in use so as to minimise evaporation. Gill (111) advocated grinding the porcelain mix in an agate mortar and pestle. He considered that this procedure would thoroughly saturate each porcelain particle and also obtain a more uniform mixture of colours. He also advocated allowing the mix to stand for some time in order to further permit the particles to become saturated.

Doner (120) also agreed with this last statement. In the discussion following presentation of a paper by Gill (142), L.E. Myers expressed doubt that the individual particles of porcelain actually absorb water, and so he did not see the necessity for allowing the porcelain mix to soak before use. The procedure of soaking may have been valid for some of the early porcelains, but as modern ones do not apparently contain kaolin or any other binder, it now appears to be unnecessary.

During the building and contouring of a porcelain jacket crown, it is necessary at times to maintain or alter the consistency of the porcelain mix by the addition of water. At such times the porcelain should again be mixed and vibrated to maintain an even distribution of the particles, and to remove any entrapped air. Johnson, Phillips, and Dykema (264) advocate that the porcelain be transferred to the matrix with a spatula or bladed instrument rather than a brush, as air is more likely to be incorporated when using a brush. This seems reasonable but there are times, such as when touching up contact points, when a brush seems more suitable for applying the porcelain. Clark (92) suggests that the water content of the porcelain on the matrix be maintained by the use of a fine atomiser, which seems a better way than touching the porcelain at one point with a wet brush.

Condensation of dental porcelain aims at orienting the particles against the platinum matrix in such a way that their centres of mass are at the shortest possible distance from one another. As it has thus far proved impracticable to devise a method of pressure moulding which will actually crush the porcelain particles into even closer proximity, other methods have had to be sought, and these make use of vibration, pressure, and surface tension.

The fact that the porcelain particles cannot be crushed by our present methods makes the nature of these particles important. We know that they are small, irregular in shape, and that no binder other than water is generally employed in the process of condensation. Hodson (203) says that the retention of shape by porcelain after condensation depends primarily upon the amount and distribution of the different sizes of particles since no binder was added to the powders. It should be noted that the surface tension of the water remaining after condensation does act as a binder holding the mass together. This can be readily demonstrated by drying out the built up crown thoroughly, by which time it will have become considerably more friable. Hodson says that when the porcelain particles are screened to one uniform size and vibrated into a container, the volume of the void spaces between adjacent grains is almost 45% of the bulk volume.

Two sizes of particles, a coarse and a fine, when thoroughly mixed together will reduce the void space volume to 25% of the bulk volume. The most efficient packing results when three or more different sizes of particles are present, even then the void space is reduced to no less than 22% of the bulk volume. She concludes "Thus it is apparent that the minimum volume shrinkage to be expected from melting together of the porcelain particles during firing is approximately one fourth (25%)." Here Hodson appears to be making two unwarranted assumptions. Firstly, that all the particles will be completely melted during the firing process, whereas they may only be so at or near the surface of the restoration (unless it has been overfired), while in the deeper layers the particles are merely welded to one another at points of contact. Secondly, she assumes that all air and other gases are completely eliminated from the porcelain during firing, whereas even when the vacuum firing process is employed, numerous very small voids remain in the porcelain.

UNFUSED?

Hence the volumetric firing shrinkage of a well condensed porcelain should be somewhat less than 25%. The exact figure is of little practical significance, but it is obvious that the less it is the better. Many conflicting figures are given for the shrinkage of dental porcelain on firing, especially in the earlier literature, and figures range from 5 to 30%. A good deal of the confusion has arisen because the writers did not differentiate between volumetric and linear shrinkages.

In another paper Hodson (204) found that most of the porcelain powder was finer than 325 mesh. She concluded that the small particle size is a factor in the forming procedure, as no binders are used with fritted porcelain. Close packing of the particles is accomplished by vibration and by control of the water content.

Felcher (135, 107) and later Megaw (245) concluded after a series of unspecified "tests" that the degree of porosity of the fired porcelain was the same regardless of the method of condensation employed. However they did recognise that poor condensation would result in excessive firing shrinkage, as did most other writers.

If the particles are small and adequately condensed so that they are in close contact with one another, then the porcelain should require less firing to achieve the desired degree of vitrification, and as a result its physical properties will be optimal. Also, as there is less space for included air in the mass before firing, there is likely to be less in it after firing. That is, the fired product should be dense and translucent. These happenings are readily confirmed by practical experience and testing.

Conversely, if the degree of condensation has been poor, that is, if the particles are more widely separated, then the liquid phase will have to flow greater distances in order to achieve the desired degree of vitrification.

To achieve this higher degree of flow, the porcelain will have to be fired to a greater degree. This has the effect of -

(1) Lowering the strength of the finished restoration. Most authorities agree that overfiring has a damaging effect on the physical properties of the finished product.

(2) Tending to alter the effect of the pigments in the porcelain, as prolonged exposure to high temperatures tends to change their colour.

(3) Causing some degree of slumping of the mass of porcelain due to its greater tendency to flow when overfired. This will result in loss of the desired form of the restoration, and the only satisfactory solution is a complete remake.

Additionally, poor condensation will result in the trapping of excessive amounts of air within the mass of porcelain, and this air is not entirely eliminated in the firing process, even when vacuum firing is employed. The result is a porcelain of excessively porous structure, lowered strength, and a milky, opaque appearance.

Having established that a high degree of condensation prior to firing is a very desirable goal, the next step is to examine the best way of achieving it.

TECHNIQUES FOR FORMING AND CONDENSING THE PORCELAIN

1. Attempts to form up the crown without utilising either the working model or some kind of matrix or mould will result in poorly condensed porcelain, because condensation will depend entirely upon the effect of the surface tension produced by absorbing some of the water from the porcelain mix. Vibration will only tend to move the porcelain from one place to another on the platinum matrix without condensing it, and spatulation will have the same effect. Whipping with a brush may be of some slight assistance, but the overall effect will be most disappointing, and in any case the method does not simplify the achievement of correct contour and contact points. To sum up, there is nothing to recommend it.

2. The method which utilises a paper matrix appears to have been introduced by Buell (26) in 1920. Buell utilised glazed paper but other workers made use of cellophane, celluloid sheet, an oversized celluloid crown form, waxed paper, and tinfoil in order to achieve the same result. The die and platinum matrix were removed from the working model and waxed paper or one of the other materials was wrapped around the die to form an open tube. Into this tube body or cervical coloured porcelain was gradually added and vibrated until the tube was full. Vibration was then continued and the water rising to the surface was absorbed

until no more appeared. The paper tube was then removed (in the case of the celluloid crown form, this was slit with a sharp knife) and the body porcelain was cut back to the required level. Another paper tube was formed and the incisal colour was added in the same way and condensed. The tube was again removed and the porcelain gradually trimmed until the die could be replaced in the working model. Carving was completed and more porcelain was added to the contact points and the crown fired.

Howard (39, 90) used this technique in 1925 and criticised previous methods of spatulating the porcelain onto the matrix. He stated that if porcelain is spatulated onto the matrix it is rather fragile and falls off easily when dry, but if it is packed inside a paper matrix and condensed by vibration until all the moisture comes to the surface and is blotted off, when the paper matrix is removed the porcelain is almost like a stick of chalk and can be handled with less care, and carved like a piece of plaster. However Howard stated that he had trouble in securing the correct colour blending and distribution with this method and for this reason used it only on posterior teeth.

Selberg (83) refined the technique somewhat in 1931 by utilising two working models. One had the contacts of the adjacent teeth reduced so that the oversized mass of porcelain on the matrix following removal of the paper tube could be carved to approximate shape prior to firing. The second model was used to correct contour and contact points after the initial firings. Selberg preferred to use an oversize crown form open at the top rather than a paper tube, but the principle was the same. His method of correcting the contact points on a second model was a distinct improvement to attempting to add more porcelain to the contact points of a thoroughly condensed crown. In the latter case a considerable amount of water has to be added before the new porcelain will attach itself, and there is a distinct danger that this will disturb the carefully achieved particle arrangement.

In discussion following presentation of a paper by Gill (142) in 1932, R.C. Wheeler stated that he considered the paper matrix method was not very practical because of the need for correct form, contact points etc., and he did not see that it was possible to avoid using other methods, such as spatulation, for part of the procedure. This criticism is answered by Selberg above.

Gill (111) claimed in 1937 that porcelain condensed in some form of paper matrix gave a better finished result than any other method employed. Gill was one of the chief enthusiasts for this method and there is no doubt that it does produce excellent condensation of the porcelain. Gardner (130) was still using this method in 1939, but in

1940 Cohen (157) and others criticised the technique on the grounds that it is very difficult to gauge the correct placement of the colours and to blend them to the desired degree. The vibration employed tends to scatter the colours, and the only way this can be overcome is to fire each colour separately, as advocated by Selberg (83). This will lead to overfiring of the deeper layers, unless porcelains of progressively lower fusing points are used. Since they must have the same or very similar coefficients of expansion this presents problems, as manufacturers do not normally produce a range of porcelains having varying fusing points and the same coefficient of thermal expansion.

Since Gill (139) adopted another method in 1946, interest in the paper matrix technique appears to have waned and little is now seen in the ceramic literature concerning it.

3. It is difficult to say when the method of building up the porcelain on the matrix and die placed in the working model was evolved. Cohen (157) described it in 1940, but it was probably in use considerably earlier. The porcelain is applied to the matrix with a spatula, holding a clean napkin or tissue on the opposite side of the matrix. Model and die are gently vibrated to bring moisture to the surface of the porcelain, and this moisture is absorbed with the free end of the napkin. The model and napkin are then

reversed, and the porcelain is packed on the opposite side of the matrix, following the same procedure as before. Cohen recommends that this be followed by whipping in order to achieve further condensation. Die, matrix, and crown are then removed from the model and the contact areas built up with additional porcelain in order to compensate for firing shrinkage. Precisely the same method is advocated by Radermacher (273) in 1961. The various colours are readily placed while building up the labial surface. Excellent condensation can be attained with this method by the expert, but it requires the development of considerable manual dexterity and constant practice in order to consistently produce thoroughly condensed crowns. The control of the water content of the porcelain is critical with this method as surface tension plays an important part in the condensation.

The less expert operator tends to work with the porcelain too dry, and this results in trapping air between the increments of porcelain. This included air is liable to cause porosity in the finished crown, even when vacuum firing is employed, producing a milky opaque appearance in the porcelain. It is better practice to maintain the porcelain fairly moist with this method until building and forming are complete.

4. A development from the previous method is the use of a rigid (but removable) linguo-incisal core on the working model. Polack (137) and Klaffenbach (165) both give Clark (136) the credit for developing this technique in 1932. Cohen (157) also made use of it in 1940.

A slightly oversize linguo-incisal contour is shaped up in wax on the die in the working model. It should be 1 to 1.5 mm. longer incisally than the finished crown to allow for shrinkage of the porcelain during firing. The linguo-incisal core is made by softening a small piece of modelling compound and adapting it against the lingual and incisal surfaces of the wax contour and the adjacent teeth, extending it about 2 mm beyond the incisal edges and a short distance over the palatal portion of the working model. After it has been chilled it is removed and trimmed so that it can readily be replaced. Talcum powder is applied to the labial surface of the compound core and a piece of tinfoil burnished over this surface folding the ends over onto the lingual area to hold it in place. Cohen (157) suggests that the tinfoil be adapted first, then the compound but this is only a minor variation in technique.

The tinfoil is coated with a film of lard oil to provide a separating medium between the tinfoil and the lingual and incisal areas of condensed porcelain. The wax contour is removed and the platinum matrix cleaned.

The model is assembled and the gingival colour porcelain vibrated into position against the lingual tinfoil until the entire space between the platinum matrix and the tinfoil is filled with thoroughly condensed moist porcelain. The various labial colours are then built up and the porcelain condensed with vibration and blotting. Carving is completed and the compound core is removed, after it has been freed from the tinfoil. The tinfoil is then carefully peeled away from the porcelain. Excess porcelain is removed from the interproximal areas so that the die and crown can be removed incisally without being fractured. The concave areas on the mesial and distal are filled in with moist porcelain and properly contoured in order to compensate for shrinkage on firing. In this method the porcelain is vibrated onto a rigid base with incomplete side walls. It should give a higher degree of condensation over the previous method and require less skill on the part of the operator to ensure consistent results. Certainly, fabrication of the lingual core does not require very much additional effort.

5. The next technique consists of the formation of a partial mould. That is, one with complete side walls as well as a base, but with the uppermost surface open. Doner (120) was probably the first to use this method. In

1936 he devised the use of a two piece stone mould. A suitably oversize crown shape is built up on the die utilising a celluloid crown form and wax. Die and crown shape are then placed face down into a mix of stone in a specially made mould former consisting of a large rubber bottle cap divided by a copper strip on which is a small platform to support the weight of the die until the stone has set.

After the stone has set the two halves of the mould are separated and dipped in a mixture of 1 part stearic acid to 5 parts carbon tetrachloride (presumably to seal the stone), and then lubricated with olive oil. The mould is reassembled and the various colours of the porcelain are placed in their correct positions. The mould is vibrated lightly and the die and matrix (with the temporary crown removed) are placed in position after the matrix has been moistened. The lingual surface is then built up with the appropriate colours and vibrated and blotted for condensation. The lingual surface is then carved to shape and whipped with a sable brush. The two halves of the mould are separated and the crown smoothed with a brush before firing. The chief criticism of this method is the difficulty of removing the two halves of the mould without fracturing the porcelain, however it should provide adequate condensation.

Baker (215) devised a method in 1960 which resembles

Doner's somewhat. Baker stated that he brought the principle of vibration of the liquid mix in a rigid, side-walled mould while applying pressure from above with a spatula, to the attention of the dental profession in 1950. However, the exertion of pressure via a spatula, while vibrating the mould, appears to be the only feature with any degree of originality. Baker attempts to study the physical principles involved in the condensation of dental porcelain, but his efforts throw little light on the situation.

An example - "The weight of the tiny ceramic particles very nearly cancels out the weight of an equal amount of water". As the true specific gravity of porcelain powder is approximately 2.4, the above statement is hard to reconcile with fact.

Baker utilised an oversize celluloid crown form placed over the die in the working model. The labial surface is cut out to allow intake of the porcelain mix. The crown is built up in the usual way, adding the gingival colour first and then condensing it and cutting back, followed by placement of the incisal colour etc. All this is done with the die in position in the working model. The assembly is gently vibrated while the porcelain is pressed down with a spatula. Baker is rather vague regarding the details of this technique, such as how he compensates for mesiodistal firing shrinkage, and how the porcelain is separated from the mould. This method differs from the previous one in that the porcelain is packed into the mould from the labial instead of from the lingual side.

6. In 1946 Gill (139) stated that he was introducing a new method of condensation, differing from any other previously considered. He said that it was not to be implied that this was a new invention, but so far as he knew it was the first time the application of a mould for the vibration of porcelain in the construction of a dental restoration had been used. Actually, partial moulds had been used before by such workers as Doner (120) but Gill's mould completely enclosed the porcelain, except for a sprue hole down which the porcelain is poured. Gill's mould consists of three sections, and when assembled, the only opening is a sprue hole through which the porcelain mix is poured. The technique is worth considering in detail, as it is original. See illustrations on following pages.

First a trial crown is made up of yellowish grey wax over a 0.003 inch tin foil matrix. It is tried in the mouth and any adjustments to correct contour are made. Occlusion is checked and any variation of surface texture is noted. After this trial wax crown has been completed, a slight addition on the incisal is made. This is to allow for increase in length to permit a slight amount of grinding

FIG. 1. WAX MODEL IN POSITION ON THE PREPARATION.

FIGS. 2 AND 3—(LEFT) .003 TIN FOIL BURNISHED OVER MODEL. MODEL WITH WAX VENT FORMER IN LINGUAL SECTION OF MOLD.

FIG. 4—(RIGHT) MAKING THE LATERAL SECTIONS OF THE MOLD.

Figs. 1-14 Reproduced From J.R.Gill's Paper, Reference (139)

FIG. 5. SECTIONS OF MOLD SEPARATED WITH MODEL IN LINGUAL SECTION.

FIG. 6. SECTIONS ASSEMBLED SHOWING VENT IN WHICH WATER IS POURED AND HYGROSCOPIC WATER IS REMOVED.

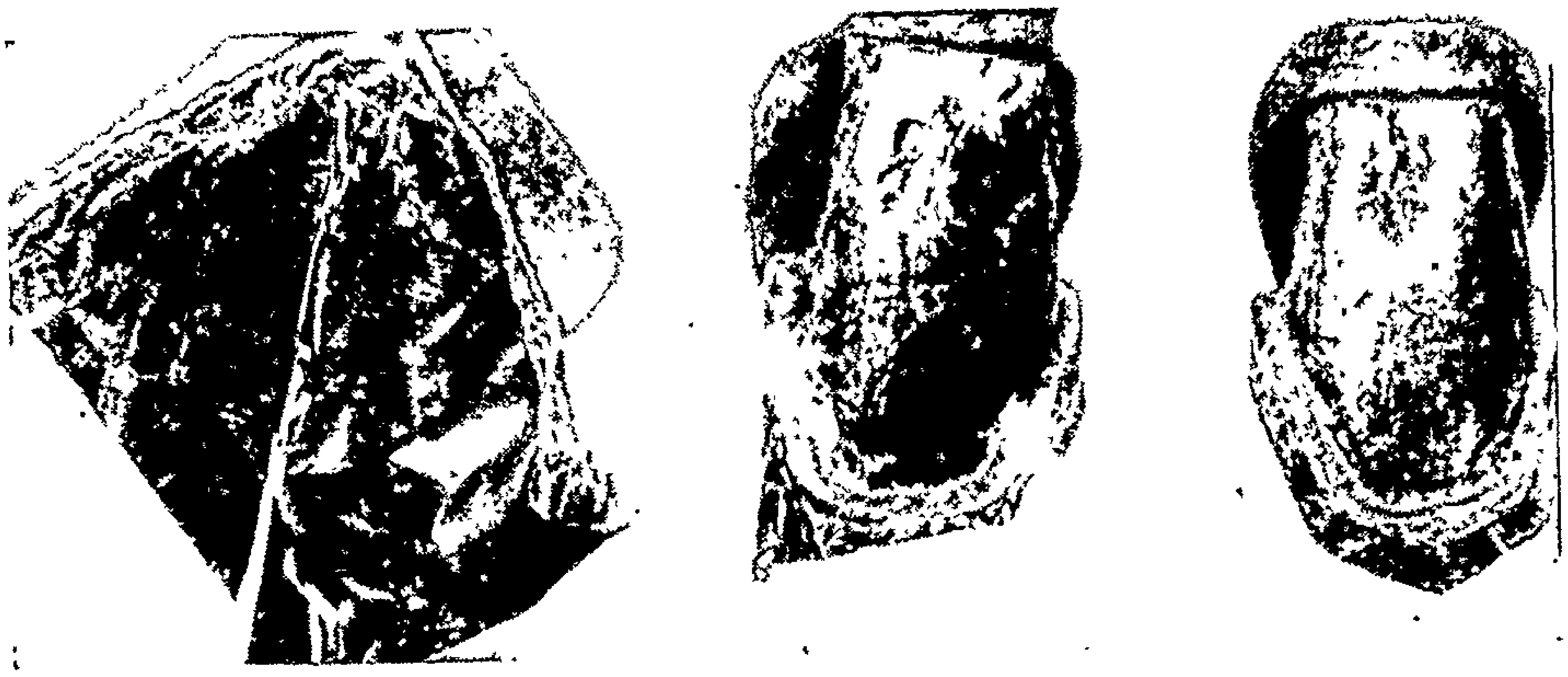


FIG. 7. SHOWING THE STEP IN THE MAKING OF THE PLATINUM MATRIX.

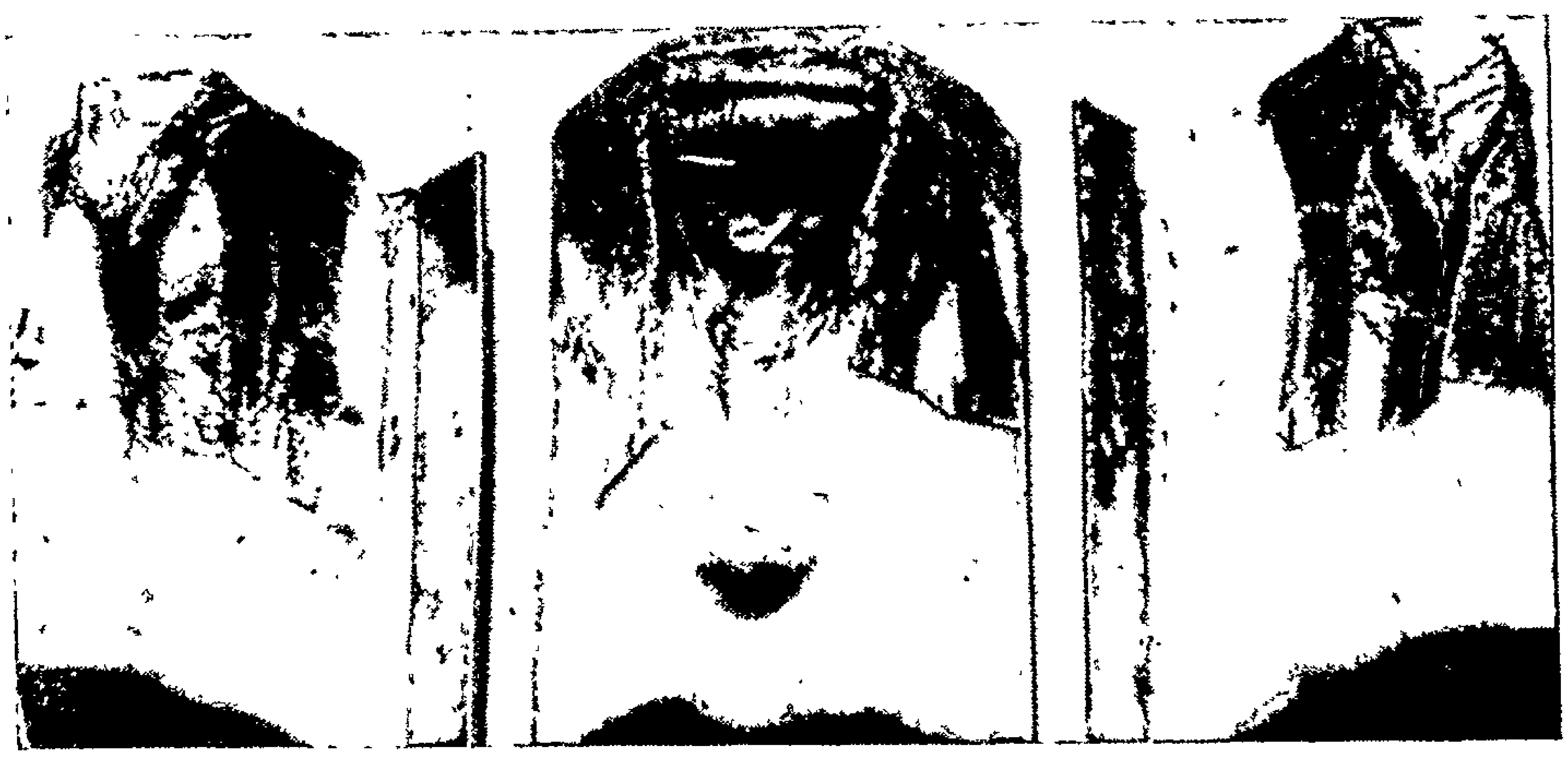


FIG. 8. TIN FOIL .0005 BURNISHED IN MOLD TO PREVENT WATER IN PORCELAIN BEING ABSORBED INTO MODEL AND ALSO SO CONDENSED PORCELAIN CAN BE REMOVED FROM MOLD.

FIG. 9. DIE AND PLATINUM MATRIX IN POSITION IN LINGUAL SECTION OF MODEL.

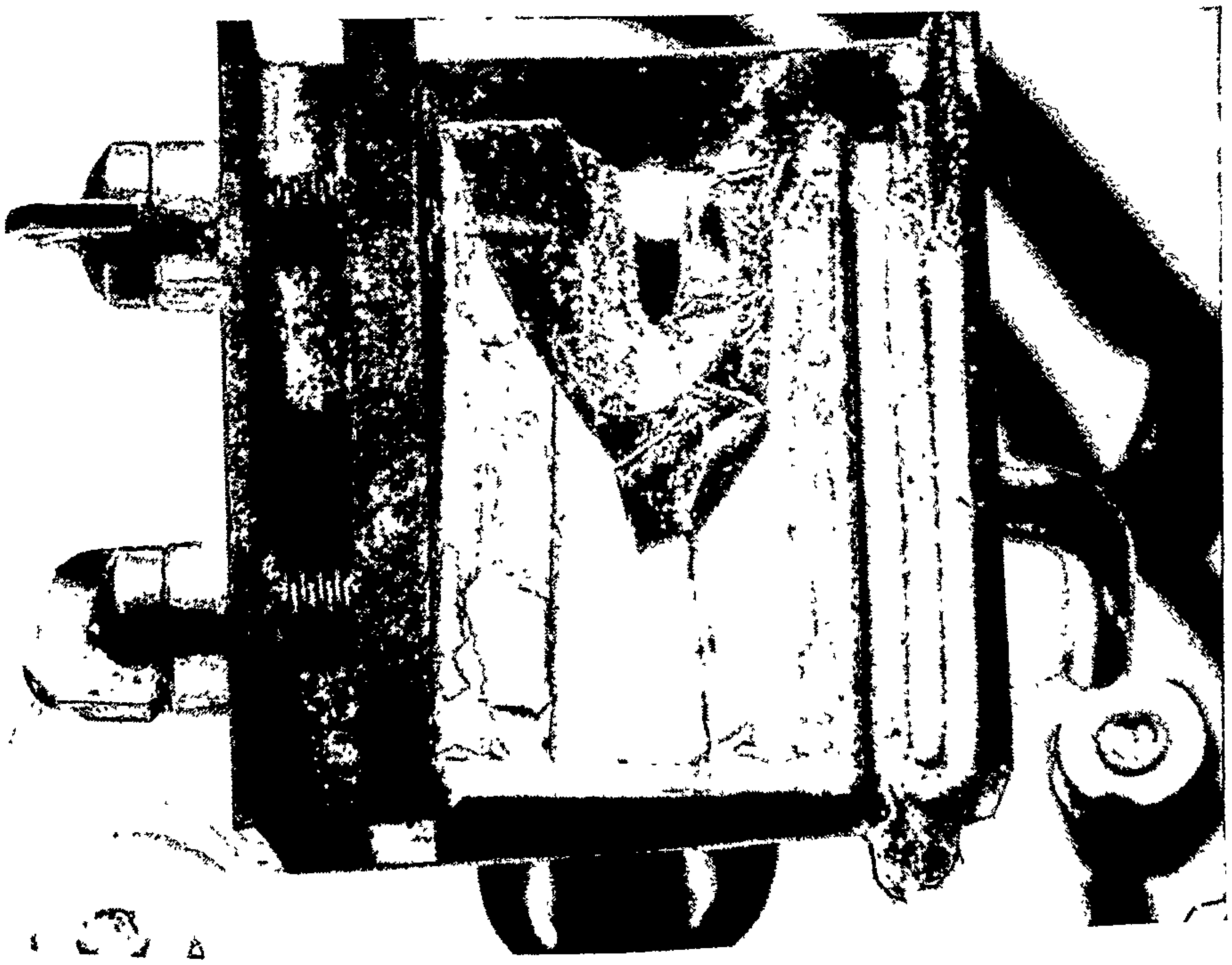


FIG. 10. MOLD IN POSITION IN VISE FOR VIBRATOR.

FIG. 11. TWO LATERAL SECTIONS REMOVED, SHOWING CONDENSED PORCELAIN IN LINGUAL SECTION.

FIG. 12. EXCESS PORCELAIN THAT FILLED THE VENT IS REMOVED, SHOWING THE ANATOMICAL REPRODUCTION OF THE LABIAL SURFACE OF THE ORIGINAL MODEL.

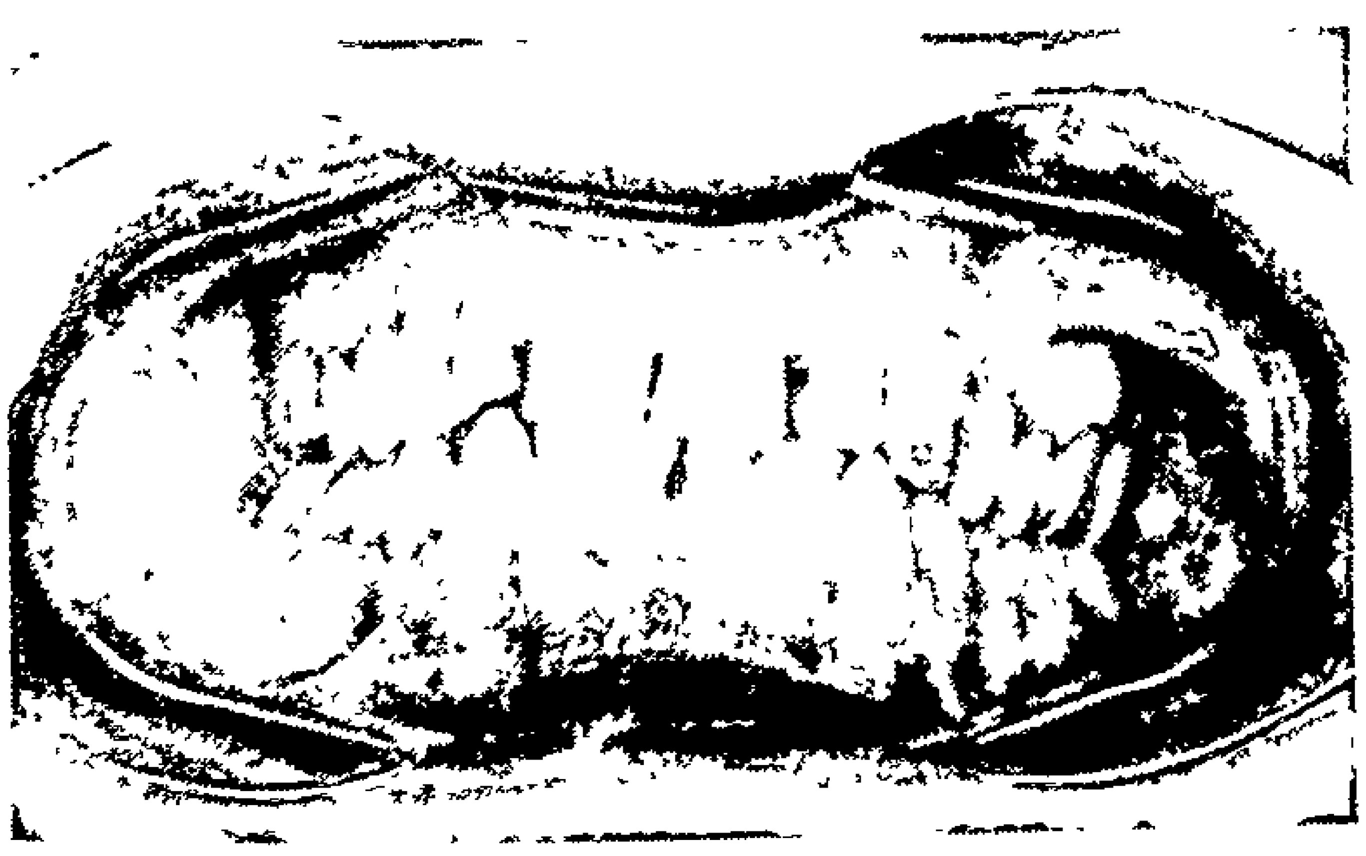


FIG. 13. FIRED CROWN PLACED IN POSITION IN THE MOUTH TO DETERMINE THE TYPE OF GLAZE NECESSARY TO OBTAIN THE PROPER ESTHETIC VALUE.

FIG. 14. PORCELAIN CROWN RECEMENTED.

after the restoration is cemented into place to simulate wear. The reason for this is that on glazing, all surfaces round slightly and grinding is necessary, especially on the incisal.

The trial crown is replaced on the die and covered with 0.003 inch tin foil to just below the shoulder level. The reason for burnishing this tin foil over the wax crown is to slightly increase the size of the subsequent mould in order to compensate for shrinkage of the porcelain during firing. The tin foil is carried below the shoulder on the die in order to later permit space for seating the platinum matrix, when the die is placed in position in the mould.

A groove is made on the die as a guide for positioning in the mould. A stone mould is made up around the die and foil-covered wax crown, to which a wax sprue former has been attached. The sprue former leads from the labio-incisal area of the crown to the end of the mould. Gill advised that the sprue should be about 2 mm. in diameter and 4 mm. in length. When set the mould is dismantled, the crown removed, and the wax flushed out of the sprue hole.

Gill states that the platinum matrix must be airtight, otherwise he warns that porcelain will flow through onto the inside of the matrix. For this reason he advises the use of a matrix with soldered seams, however it should be sufficient to seal a tinner's joint by firing a thin layer of porcelain over it. The matrix apron should be of uniform width and follow the outline of the shoulder. Shellac is placed on the shoulder to permit the porcelain to separate from it during the first firing. The inside surfaces of the mould are covered with 0.0005 inch tin foil, one piece for each section of the mould. The tin foil acts as a separating medium, and Gill considered it to be the most effective he had tried up to that time.

The mould is assembled with the die and matrix in position. Gill suggests that the three pieces of the mould be locked together in a vyce on the vibrator, but it should be possible to key the sections and bind them together with cord to serve the same purpose.

The gingival colour is vibrated slowly into the mould first, and Gill recommends that a high fusing porcelain be used. Vibration should be carried out for 15 minutes after the mould has been filled, without absorbing any water. For the next 15 minutes the water is alternatively absorbed and more porcelain added until the mould is completely filled with densely packed porcelain. Gill warns that if the water is eliminated too rapidly, porcelain at the base of the mould will not be thoroughly condensed, and will have a flaky consistency. This he says is because water is withdrawn from the upper layer and the porcelain in this area becomes so condensed that it will not permit the water from the lower portion to find its way to the surface.

After the porcelain has been thoroughly condensed the two lateral sections of the mould are carefully removed. To remove the condensed porcelain and die from the lingual section, the ends of the tin foil are lifted, and the tin foil is then peeled away from the porcelain. The sprue of porcelain is trimmed away, and Gill states that the result is a condensed porcelain crown exactly as the wax crown plus 0.003 inch all round.

The condensed porcelain is then trimmed back to the outline of the dentine colour as shown on the colour chart. The crown is fired to a high biscuit bake and the platinum readapted in the shoulder area where shrinkage of the porcelain has occurred. The shoulder area is filled in with porcelain and any desired stains added. The crown is fired again at the same temperature.

Once more the inside of the mould is lined with 0.0005 inch tin foil and assembled with the die and crown in position. The incisal colour is vibrated into the mould and this time Gill recommends the use of a medium fusing porcelain, so as to avoid subsequent overfusing of the dentine colour, which has already been fired twice. Condensation is carried out as before and the mould dismantled. The porcelain sprue is removed and any fine carving carried out. It is now ready for final firing and finishing.

Gill rightly considers that his technique will consistently produce a porcelain crown with the highest degree of condensation, even in comparatively unskilled hands, because it is a purely technical procedure. Gill claims that the time involved in making the trial crown is compensated by the results obtained. The method probably requires more chairside visits (for try-ins) than do other methods, but the end results are probably more dependable. To be able to produce crowns with the same degree of condensation time after time should solve many of the colour problems now experienced. Failure to match the desired colours in a porcelain jacket crown can be caused by variations in the thickness and distribution of the colours, but in my opinion is more often caused by lack of condensation of the porcelain. Gill's technique requires four firings, but most other techniques require at least three, so this does not appear to be too serious a disadvantage. In any case he attempts to overcome this by using two porcelains having differing fusing ranges but compatible coefficients of thermal expansion. This solution is difficult to apply today, as few manufacturers now make a range of porcelains with differing fusing ranges but compatible coefficients of thermal expansion.

Gill's method appears to have a good deal to recommend it, and any deleterious effect on the basal layer of porcelain by only one extra firing would probably be more than compensated by the advantage of securing the maximum possible condensation by our present known methods.

In 1932 Gill (142) attempted to evaluate experimentally the different means then available for condensing porcelain for a jacket crown. He classified the different methods as whipping, spatulating, gravitation (not very clear what he means by this), vibration without a matrix (mould), vibration in a matrix (presumably with the serrated handle of an instrument), and mechanical vibration in a matrix (presumably with an electric dental vibrator).

The specimens used measured 13 mm. in length, 10 mm. in width, and 4 mm. in thickness. The accompanying table gives the results of the tests.

Method of Condensation	Transverse Strength (p.s.i.)	Percentage Density	Percentage Water Loss
Spatulating	11.20	2.33	18.16
Whipping	9.55	2.31	19.06
Vibrating in matrix	14.00	2.37	11.00
Vibrating without matrix	8.96	2.23	14.20
Gravitation	12.90	2.34	14.80
Mechanical vibration in matrix	14.03	2.35	19.81

Gill says the dry modulus of rupture determines the transverse strength of the dried mix in its unfired state. The test was applied to determine the transverse strength of each specimen prepared by the various methods of condensation before firing.

The dry modulus of rupture was determined by placing the specimen on two bars which were 11 mm. apart. A pan was suspended from the centre of the specimen and shot were dropped in the pan until the specimen broke. The shot and pan were then weighed.

$$\text{Transverse strength} = \frac{3 \times \begin{matrix}\text{breaking load}\\ \text{in pounds}\end{matrix} \times \begin{matrix}\text{distance between}\\ \text{supports in inches}\end{matrix}}{2 \times \text{breadth in inches} \times \text{depth in inches}}$$

Gill states that the test was applied to the dried mix, but does not state how drying was accomplished. Any residual water would have a considerable effect on the transverse strength. It does not seem a test from which conclusions can be drawn.

The density of the condensed <u>and fired</u> porcelain was obtained by weighing the specimen first in air, then in water.

$$\begin{matrix}\text{Percentage}\\ \text{density}\end{matrix} = \frac{100 \times \begin{matrix}\text{weight of specimen}\\ \text{in air}\end{matrix} - \begin{matrix}\text{weight of specimen}\\ \text{in water}\end{matrix}}{\text{Weight of specimen in air}}$$

The loss of water during drying was measured by heating the specimen to different temperatures. The specimen was weighed before placing in the oven and weighed at intervals of 200°F. The loss of weight in the specimen indicates the amount of water eliminated from each.

$$\text{Percentage water loss} = \frac{\text{original weight} - \text{fired weight}}{\text{last weight}} \times 100$$

A criticism here is that for the test to have some significance, the temperature of the oven must rise at the same rate for each test, or the specimens must be heated and weighed simultaneously. Obviously water loss depends on time as well as temperature. This is borne out by the results, which do not appear to follow any logical pattern.

Gill says that specimens prepared by various methods of condensation were X-rayed to determine their density and homogeneity. Other specimens were X-rayed after firing at different temperatures to determine the changes and effects of firing. Glazed specimens from each method of condensation were also examined in this way. Results:-

1. Spatulating showed many voids and lack of uniformity in structure.
2. Whipping showed a similar picture.
3. Vibrating in a matrix showed uniform structural arrangement.
4. Vibrating without matrix - not mentioned.
5. Gravitation showed few voids and fair uniformity in structural arrangement.
6. Mechanical vibration in matrix showed a uniform structure with only a few voids.

Gill concluded that vibration in a matrix, either mechanical or by hand, is the most satisfactory yet presented. In this case Gill's conclusion appears far more sound than the experiments on which it is based. However it should be remembered that these tests were carried out over thirty years ago, and a great deal more fundamental knowledge of dental porcelain and its condensation has been discovered since. However, in my view, a thorough, scientific, and unbiased survey of the fundamental principles behind condensation of porcelain, and their application to the building of porcelain jacket crowns, has yet to be published.

FIRING OF DENTAL PORCELAIN

The condensed and carved crown is fired in a small furnace. Le Gro (52) stated that from 1875 to about 1890 coke, crude oil blast, gas, and gasoline furnaces were used. The noise and odour produced by the gasoline and oil furnaces were objectionable, and uniform firing was difficult. Gassing of the porcelain was a very common trouble with the gas and gasoline furnaces owing to rapid disintegration of muffles with this type of apparatus.

About 1894 Custer (5) introduced the first electric dental furnace for firing porcelain. A rheostat was used to control the furnace and fine platinum wire formed the heating resistance. The platinum wire was exposed inside the muffle and thus subject to damage by having bits of porcelain or other foreign substances come into contact with it during operation. As this particular muffle was not removable, repair was a decided inconvenience.

According to Cohen (154), the Hammond furnace appeared in 1899 and it had a detachable muffle which made repair a far more simple matter. Neither of these furnaces had a pyrometer, and the operator had to inspect the work to determine the degree of firing accomplished. However the steps on the rheostat did give some idea of the temperature of the muffle when the operator had experimented for some time.

Cohen (158) stated that soon afterwards the electric pyrometer was adapted to the electric dental furnace by Weston A. Price. The introduction of porcelains with a lower fusing range enabled the expensive platinum winding of the muffle to be replaced with cheaper base metal alloys such as nickel-chromium. Otherwise the basic layout changed very little until recent years. The latest developments have been in the field of automatic controls and in the evacuation of air from the muffle at certain stages in the firing process. Diffusible gas methods have not so far been incorporated in dental furnaces intended for the firing of porcelain jacket crowns and other dental restorations.

The basic parts of a dental porcelain furnace are:-

1. Muffle
2. Indicating system
3. Control system

The muffle consists of a chamber surrounded by a coiled wire heating element. In most furnaces the wire is separated from the chamber by a thin layer of insulating material, but in others a substantial part of the wire is uncovered. A very thick layer of insulating material prevents heat from escaping the muffle chamber to the outside air. A fireclay door is used to close the chamber, and if the furnace is intended for vacuum firing the muffle must be able to be made airtight so that it can be evacuated at the appropriate stage in the firing process. Thermocouple wires project into the chamber of the muffle, and are situated so that the work to be fired can be positioned as closely as possible under the junction of the two wires.

Until fairly recent years the indicating and control systems were separate. The indicator consisted of a pyrometer calibrated in degrees Fahrenheit or Centigrade, or both. The control system consisted of a rheostat, or variable resistance. Within the last fifteen years the indicating and control systems have been linked by various means to provide different degrees of automatic control for the furnace.

Automatic controls add considerably to the initial cost of the furnace, but they do free the operator from the very tedious task of watching the pyrometer and the clock, and in certain techniques (e.g. Vita) they probably speed up the process of fabricating a porcelain jacket crown.

Both the muffle winding and the thermocouple wires are subject to deterioration with continued use. Felcher (135) states that the platinum thermocouple wire can volatilise to some extent, while the other one, which usually contains rhodium, does not. Consequently the platinum wire gradually becomes thinner with age and the pyrometer becomes inaccurate. The pyrometer should be checked periodically and recalibrated if necessary. This can be done with the aid of a piece of gold foil which melts at exactly 1945°F, or by using Thermil tablets which melt at specified temperatures. The muffle winding will also be affected by volatilisation or oxidation, and its resistance will tend to increase with age. Hence for the muffle to reach the same temperature, more current will have to be applied as the muffle ages. Eventually both muffle and thermocouple may have to be replaced. Muffles intended for use with medium and low fusing porcelains have a far lower replacement cost, as they are wound with base metal alloys instead of platinum.

Porcelain jacket crowns are usually placed in the furnace mounted on fireclay crown stands. In the past they were often placed on flat trays, but easily toppled over with disastrous results. It is not advisable to use ground silex or quartz trays in the furnace, as pieces of this material (SiO_2) remaining in the muffle will melt after a number of firings and may attack the muffle winding at high temperature.

The firing of dental porcelain is a pyrochemical reaction requiring both temperature and time for its accomplishment. With the older, non-fritted porcelains there was considerably more chemical reaction involved than in the fritted porcelains more commonly in use today. Skinner and Phillips (251) state that since the pyrochemical reactions between the ingredients have been virtually completed in most cases during the original fritting process, the purpose of firing is simply to fuse the particles of powder together properly. Hodson's work (199) supports this statement. She found that the firing of dental porcelains failed to produce any phase different to those already examined in the powders.

Iwansson (86) writing in 1931 said that the advantage of maintaining a relatively low final temperature constant for a certain number of minutes is that the porcelain is fused, not only on the surface, but also approximately as much in the interior of the crown, thereby gaining much in strength. He considered that this method tended to be less critical, and that the life of the furnace muffle is increased.

Megaw (245), on the other hand, writing some thirty years later, states that dental porcelain is strongest when slightly underglazed. Aesthetics demand a glazed surface, and so to have the strongest material combined with the best appearance, a dental porcelain restoration should be fused at a definite temperature within a certain time, which will produce a glazed surface without extending the glaze too deeply.

Clark (92) writing in 1935 contrasted the slow firing methods used for porcelain jacket crowns with the rapid firing methods used in the manufacture of porcelain artificial teeth, and questioned whether these slow firing methods were really necessary. However it should be remembered that a jacket crown is thinner in section and more complex in shape than is a porcelain tooth, and for this reason is more likely to distort under rapid changes in temperature. Clark says the texture is best, and the strength of porcelain greatest at the point where vitrification is complete. He states that we necessarily sacrifice both texture and strength in order to produce translucency and a glazed surface.

It is generally accepted desirable to terminate the firing as little beyond the stage of complete vitrification as possible, in order that the porcelain should have maximum strength. With air fired porcelain, a large powder particle size is necessary to obtain satisfactory translucency. The surface of vitrified air fired porcelain is porous, and hence it is necessary to carry the firing considerably further in order to produce sufficient flow to obtain the desired glaze.

With vacuum fired porcelain, the particle size of the powder is kept very much smaller as this has no effect on the translucency of the fired product. This, plus the added densification and greatly reduced porosity due to the vacuum firing process itself, allows the formation of a satisfactory glaze without having to carry the firing very much further than the vitrification stage.

It is difficult, if not impossible, to discuss the pyrochemical changes involved in the firing of dental porcelain due to our present state of ignorance regarding the composition and manufacture of the dental porcelains in current use. Gill (134) attempted to examine the pyrochemical changes involved in the firing of dental porcelain in 1931, but his paper was confined to generalities, as have been most of the papers published since on this subject. One is on much safer ground in discussing the physical changes involved in the firing process, as these can be observed.

Stages in Firing

1. Drying out. Clark (92) says that placing the condensed crown for two to three minutes on top of the warm muffle, or near the open muffle door, is sufficient time for drying out. Radermacher (273)

advises six to seven minutes are necessary, but Clark claims that cracks and checks sometimes attributed to a too rapid dehydration are usually the result of insufficient condensation, or failure to relieve one of the forces of shrinkage. It would seem reasonable that when the porcelain is fairly thick and has been well condensed, a longer time is necessary to allow the expanding water vapour to pass via the tiny interstices between the porcelain particles without exerting sufficient pressure to disturb the particle arrangement. Modern porcelains intended for vacuum firing have smaller particle size, which means smaller interstices through which the vapour can escape. Hence it would be prudent to allow adequate time, say seven to ten minutes, for this stage to be accomplished.

2. Skinner and Phillips (251) state that a low bisque firing is the stage when the fluxes have softened and have started to flow between the particles. The fired article exhibits rigidity, but it is very porous. The powder particles lack complete cohesion. A negligible amount of firing shrinkage can be noted.

3. A medium bisque firing is characterised by the fact that the fluxes have flowed to the extent that the powder particles exhibit complete cohesion. The

article is still porous and this stage is accompanied by a definite shrinkage.

4. After a high bisque firing the shrinkage is complete and the mass exhibits a smoother surface. Skinner and Phillips (251) state that the body does not exhibit a glazed appearance, but in my experience it does develop a slight sheen.

5. A glaze firing is characterised by the development of a glassy surface and some degree of translucency. There is a barely discernible tendency for sharp corners to become rounded.

6. If the porcelain is overfired, there is a tendency for the translucency to increase, but this is usually more than offset by an increase in size of any gas bubbles in the porcelain, producing a characteristic milky opacity. A lightening of the colour of the porcelain may occur, due to the effect of continued high temperature on the pigments. A definite trend for the article to assume a spherical shape by rounding of corners etc. is observed. An increase in porosity is usually accompanied by a decrease in the strength of the porcelain.

Pettrow (218) states that the extent of vitrification and consequent effect on the porcelain are important. Correctly vitrified porcelain is the result of arrested firing, and overfiring seriously affects the strength of the porcelain by developing pronounced brittleness. Shade, translucency, and form are also undesirably altered or destroyed, and porosity is enlarged.

Again it must be emphasised that the transition from one firing stage to the next depends upon both temperature and time. A transition from one stage up to the next can be accomplished merely by leaving the porcelain in the furnace longer at the same temperature. This property is made use of in the Vita vacuum firing technique. The same maximum temperature is used for each separate firing, and the degree of vitrification is wholly dependent upon the time the article is allowed to remain in the furnace at that temperature. The application of this principle has permitted some simplification in the automatic controls used in the Vita vacuum furnace.

Firing Schedules

At the present time the manufacturer of a particular porcelain is probably the one best equipped to examine its behavior under different firing schedules. Outside bodies generally do not possess the necessary testing equipment, and are not informed regarding the composition and manufacture of the porcelain. For this reason the firing schedule advocated by a manufacturer for his product should be followed, unless it can be demonstrated by thorough and adequate testing that an alternative schedule produces superior results. Of course the schedules are sufficiently flexible to accommodate variations in furnace muffles, pyrometers, and in the degree of glaze desired for a particular case.

In the past some operators have advocated major changes in firing schedules published by manufacturers. This was often justified because many manufacturers at that time did not apparently experiment sufficiently with the effect of firing on their products.

The tendency now is for dental porcelain to be manufactured by only a few very large concerns, which have the facilities to undertake an adequate program of testing before a new product is released. For this reason it is reasonable to assume that firing schedules now produced by manufacturers will give superior results to those devised by outside operators who have no facilities for adequate testing of physical properties.

There is some controversy regarding the importance of annealing (i.e. slow cooling) of a porcelain jacket crown following its final firing. Gill (139) says the crown should be allowed to cool in the muffle to 400°F before it is removed. In an earlier paper (74) he stated that tests made at the University of California revealed a difference in compressive strength from 350 to 500 pounds between a specimen taken out of the furnace at 800°F and one removed below 400°F. On the other hand Felcher (135) says we must not expect too great an effect from annealing. He says that certain glasses capable of withstanding thermal shock are made so by certain formulas, irrespective of the fact that they are annealed. Lee (189) supports this view.

The position at the present time is that most of the older porcelains require careful annealing, but the newer materials are so formulated that they may be cooled at a much more rapid rate without any noticeable effect, if the manufacturer so specifies. If crowns made from the newer materials are slowly removed from the furnace muffle at the end of the holding period and placed under a glass beaker, they should be quite safe.

The two main problems arising in the firing of a porcelain jacket crown are shrinkage and porosity.

Shrinkage is to a large extent influenced by the degree of condensation attained before the crown is fired, but assuming that the condensation has been adequate according to our present known methods, the firing shrinkage will still be quite substantial. Sacchi and Paffenbarger (196) investigated the volumetric firing shrinkage of several dental porcelains in 1957 and their results are as follows:

Porcelain	Percent volumetric firing shrinkage
Apco low fusing (1024°C, 1875°F)	38
SS White low fusing (927°C, 1700°F)	38
SS White high fusing (1388°C, 2440°F)	37

Hodson (203) obtained the following results in 1959.

A. Percent Linear Shrinkage

	High	Medium	Low
Bisque	10.7	11.5	12.7
Glaze	11.3	12.4	13.7
Overfired	12.4	14.5	14.3

B. Percent Volume Shrinkage (based on dimensions of the mould)

	High	Medium	Low
Bisque	29.6	31.4	37.2
Glaze	28.2	31.3	36.6
Overfired	25.1	30.9	35.3

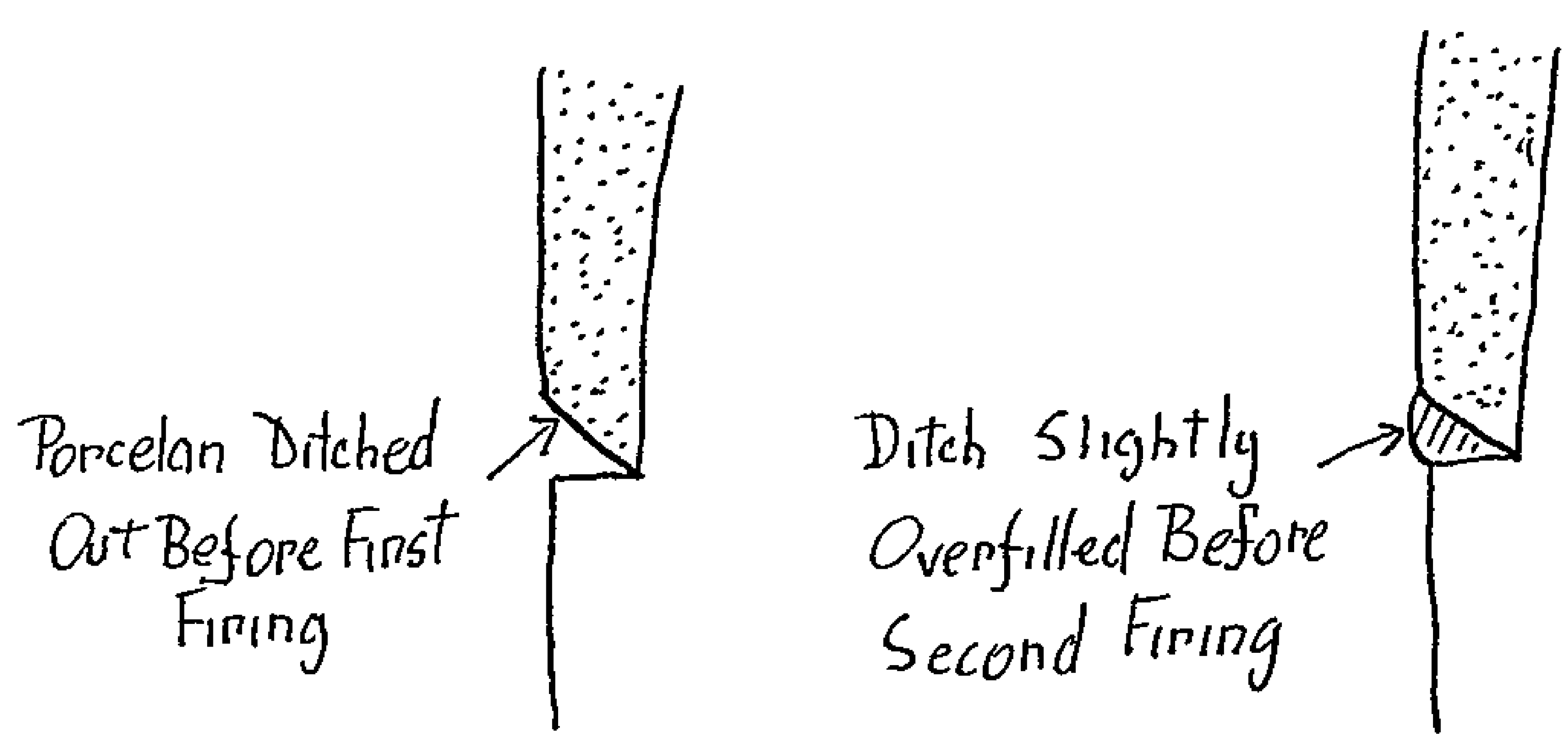
From these varied results it seems reasonable to state that the volumetric firing shrinkage of a typical dental porcelain will vary between 25 and 38 percent, and the linear shrinkage between 10 and 15 percent, depending upon the nature of the porcelain itself (composition, presence or absence of binders, particle size etc.) and the degree of condensation obtained before firing.

A good deal of confusion has arisen as the result of failure to differentiate between linear and volumetric shrinkage in the literature. The porcelain jacket crown may be described as a hollow shell, and as such linear shrinkage would appear to have a greater bearing than volumetric shrinkage.

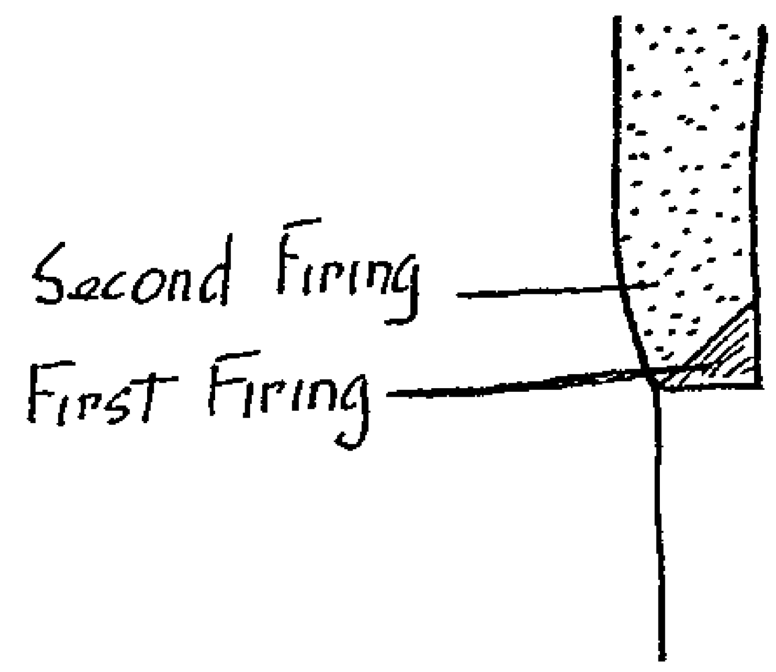
Various methods have been advocated to compensate for the effects of this shrinkage. The condensed crown is of course made suitably oversize, but if no other compensation is made and the crown fired in one bake, the resultant contraction will distort the platinum matrix and the crown will no longer fit the die.

Le Gro (53) in 1925 suggested three methods of compensation for firing shrinkage without distorting the platinum matrix:-

1. The porcelain of the first layer is ditched out slightly at the shoulder so that shrinkage will not draw the matrix from its original position on the shoulder. After firing the ditch is filled in with the second layer of porcelain.



2. The triangular space formed by the shoulder may be filled in with a fine line of wet porcelain and fired so that when the larger mass is laid on and fired the shoulder of the matrix will remain in place and so ensure adaptation at that point.



3. Le Gro himself recommended that the matrix at the shoulder be painted with a thin coating of shellac. Then an even coating of porcelain is applied over the matrix of exactly the same depth as the shoulder. Le Gro claimed that as the porcelain is of even thickness it will not shrink in only one direction at the expense of the shoulder, and in any case the shellac (which burns out at a relatively low temperature) will prevent the porcelain from pulling the matrix in this region. Le Gro stated that he had used this method for some twenty years with considerable success. Radermacher (273) employs a similar technique with the first bake of semi-opaque porcelain. She omits the shellac but advises that the depth of the layer of porcelain be only one half the width of the shoulder.

4. In 1927 McBean (43) advocated filling the inside of the platinum matrix with high temperature investment before the crown was fired in order to help the matrix resist distortion. This had the theoretical advantage of allowing the crown to be built up with fewer bakes, but it is doubtful if the investment held the platinum with sufficient strength to prevent the pull of the shrinking porcelain from distorting it. The method also prolonged firing schedules, as the investment acted as an insulating material making it more difficult to heat the porcelain evenly. Lastly, it was most inconvenient as the investment had to be scraped out before the crown could be tried back on the die. Not surprisingly it has never become a popular method.

Porosity

Excluding contamination as a cause, porosity in air fired porcelain arises as the result of air being entrapped in the interstices of the porcelain during the firing process. If the porcelain has been poorly condensed, the interstices will be larger and more air will be entrapped.

Semmelman (250) states that for many years gas bubbles have been a problem in dental porcelain. He says it has been consistently calculated that air fired porcelain contains 6.3% voids or gas, and that these pores not only result in undesirable roughness when the crown must be ground or altered, but exert an even more undesirable effect on the optical properties of the porcelain. Until 1949, he says, it was not known if the bubbles in dental porcelain resulted from gas entrapped in the raw spar, from absorbed gases, furnace atmosphere, interstitial voids, or from exactly what source they might result.

Hodson (204) stated that bubbles as large as 0.064 to 0.130 mm. were observed under the microscope in samples of air fired porcelain. In another paper she stated (199) that in many cases their development was traced from feldspar grains which were apparently an additional source of bubbles to those mentioned by Vines et al (212). They also appeared in firing translucent porcelains which were almost entirely glass. She reported that bubbles formed as clear areas in the bisque firing and became spherical and much enlarged upon further firing. The largest bubbles measured in the samples ranged from 0.03 to 0.22 mm. Many were very small when first formed but expanded with further heating, and, after the bisque stage, became spherical. Almost two-thirds of the glaze-fired porcelains contained one or more bubbles, approximately 0.10 mm. in diameter. Selberg (83) stated that a porous body of porcelain will reflect the air pockets, pits, and voids through the glaze to produce a glassy, frosted appearance instead of the smooth solid finish found in the natural teeth. The voids and flaws in the body of the porcelain, when glazed, will only be accentuated, and the minute bridges of the glaze over the air pockets near the surface fracture to form crypts which collect residue, and appear as black specks in the surface. The problem of porosity can also arise with vacuum firing, and it can be caused by poor condensation, or errors in the firing schedule, or both.

With our present methods of condensation some air is bound to be included in the porcelain before firing. Some of this air does escape, but as Semmelman states some 6% air will remain in the porcelain after normal atmospheric firing. If fine grain porcelain powder is used, then the air will be present after firing as myriads of tiny bubbles which produce an opacifying effect, due to internal reflection and refraction of light passing into them. Until 1949 the only practical method of overcoming this opacity was to increase the particle size of the porcelain powder. This did not reduce the amount of included air, but changed its distribution. Instead of myriads of small bubbles, the air was now present as smaller numbers of larger bubbles. This improved the translucency of the porcelain, but the appearance was still far from natural, the surface was still rough when ground, and the strength of the porcelain was still lowered. Porosity was recognised as a barrier to be overcome in order to achieve improvements in both aesthetics and strength.

According to Vines and Semmelman (225) in 1949, while studying factors involved in shade control, a series of experimental firings was conducted in pure gases which are likely to be present in a furnace atmosphere, and it was observed that some of the specimens were substantially free from bubbles. They state that this observation by Gatzka (246) was responsible for the first successful method of producing pore-free, desirably translucent, more lifelike artificial teeth.

In order to evaluate the results of test firings, a method for measuring porosity was developed by Semmelman (188). By using this method it was possible to develop the cause of bubbles in air fired porcelain, the reason for the influence of powder particle size on translucency, as well as the mechanisms involved in densification.

Once the water has been eliminated, the interstitial spaces in the condensed porcelain do not affect the initial firing process except to permit air to enter the mass, burn out any binder, and permit combustion products to escape into the furnace chamber. When fusion begins melting starts at the areas of contact between the powder particles, and as appreciable fusion and shrinkage take place, individual spaces are sealed by the fused material. The atmosphere sealed in the interstitial spaces is the atmosphere present in the furnace at the time the spaces are sealed-air in the case of air fired porcelain.

Vines and Semmelman (225) state that the simple explanation of densification due to vacuum firing is that the air is removed from the interstitial spaces before this sealing of the surface occurs, and hence there is nothing to hinder the porcelain from shrinking to a dense, pore-free mass. Actually, as the vacuum is imperfect, the furnace atmosphere consists of air at very low pressure. Hence what is sealed in the interstitial spaces is the furnace atmosphere at very low pressure. These spaces become spherical as the air within them expands with increased temperature and the effect of surface tension. When air at atmospheric pressure is allowed to enter the furnace it exercises a strong compressive effect on the low pressure bubbles through the medium of the semi-molten porcelain. Semmelman (188) claims that vacuum fired porcelain has an average of less than 0.1% porosity, or one sixty-third that of air fired porcelain. As this process is not affected by the particle size of the porcelain powder, it becomes possible to introduce finer powders without adversely affecting the translucency of the fired porcelain. Fine powders are easier to build and condense, reduce the void space in the condensed porcelain somewhat, and require no binder other than water. They also allow better dispersion of the pigments, and vitrify at a slightly lower temperature.

Alternative methods for securing densification during the firing process have also been developed, but as yet these have not been applied to the fabrication of porcelain jacket crowns. However it is of interest to mention them in case they are applied in the future.

Peyton et al (235) state that a diffusible gas such as helium may be introduced at low pressure to the furnace during the second or densification stage. The helium instead of air is entrapped in the interstitial spaces, and because its molecular diameter is smaller than the porcelain lattice, it diffuses outward under the pressure of the shrinking porcelain. Vines and Semmelman (225) state that either hydrogen or steam is also suitable, but Lee (267) says that hydrogen produces a reducing atmosphere which is detrimental to the pigments. It is also extremely difficult to handle because of its explosive nature. He says that helium is the most satisfactory inert gas since there is no fear of an explosion, or change in the colour of the porcelain. He reports that steam gives somewhat the same results as helium, but is not as effective. All of these methods give results comparable to vacuum firing, but are more expensive and difficult to apply, so are not likely to replace it.

In another method known as the pressure firing process, only the glaze stage is involved. Normal air fired porcelain is glaze fired in a furnace completely encased in a pressure shell, and the pressure is held at 225 p.s.i. during cooling to about 1800°F or lower. This causes the air bubbles to be reduced in size, and produces density comparable to vacuum firing or diffusible gas firing. Pressure fired porcelain may not be again fired to glazing temperatures under normal atmospheric pressure, since the compressed bubbles expand to produce the porosity of air-fired porcelain.

It would seem reasonable that the densest porcelain could be obtained by the application of vacuum up to the glazing stage, followed by pressure as the porcelain cooled. However the very slight increase in density resulting would probably not justify the additional trouble and expense of the process.

The increased translucency and lessened porosity produced by these new firing methods also changes the apparent colour of the porcelain, so that special shade guides for vacuum fired porcelain are necessary. The effect of vacuum firing on the other physical properties of dental porcelain will be discussed in the next section.

PHYSICAL PROPERTIES OF DENTAL PORCELAIN

Dental porcelain has presented many problems in evaluating its physical properties, and attempts are still being made to develop standardised tests. At present the position is somewhat chaotic, as various testing methods yield vastly different quantitative results. This is especially the case in attempting to assess the strength of dental porcelain.

Some other properties are not so difficult to determine. Seth (163) states, in general terms, that porcelain is hard, physically and chemically stable, impervious to water and bacteria, and resistant to oral fluids. It is tasteless and odourless, translucent, radiopaque, relatively colour fast, and takes a high glaze. It is a non-conductor of heat and electricity. Such properties are readily determined, at least qualitatively.

Sayre (138) writing in 1944 stated that until recently there was little known of the physical properties of baked porcelain. In a review of the literature, virtually nothing of a scientific nature was found. He reported there were a great many empiric statements regarding the physical properties, but nothing definite that could be duplicated or proved from the data supplied.

Peyton et al (235) state in 1960 that the determination of the physical properties of fused porcelain is a most tedious and time consuming study, which may explain why there are so few values reported in the literature. Such study demands extreme control of the method of sample preparation and firing conditions. They concluded that further studies of this important material for dental restorations are needed.

Semmelman (250) sounds a more optimistic note in 1962. He says we now have a series of tests which, when utilised in the proper combinations and interpreted in the light of past background and clinical correlation, is capable of evaluating practically any problem which is presently conceivable in the art of dental materials or the science of production of dental porcelain and dental products.

However, he also states, in relation to a method developed by Kulp, Lee, and Fox (219) to test impact strength of dental porcelain:- "There is not sufficient clinical correlation to ensure accuracy of this test in degree. We have arbitrarily chosen test variables producing data which reflects generally what has been reported from service, and also demonstrates our products to good advantage. In general we feel that the test is correct in principle although we may have exaggerated the degree of difference. This is something that only time and further clinical correlation can establish with greater accuracy."

As this statement demonstrates, while the bulk of physical properties testing of dental porcelain is carried out by manufacturers, we must expect them to devise testing methods which favour their own products. There is a real need for Bureaux of Dental Standards, such as the U.S. and Australian, to develop a series of standardised tests, with set methods of specimen preparation, in order to put an end to this anomalous situation.

Microscopic Examination

Felcher (135) stated in 1934 "How easy it is to be deceived when we are studying fired translucent dental porcelain under a high power glass. In the first place it is impossible to cut porcelain as other specimens, making it necessary to study it in bulk. With a high power lens, the least turn throws some portion out of focus, and this will make the air spaces look larger. When other air spaces are brought into focus, something else is blurred."

Clark (92), writing the following year, disagreed with Felcher. He considered porosity could best be studied under a wide field binocular microscope provided with objectives giving magnifications of 7 and 14 diameters. Klaffenbach (133) later agreed with Clark that these magnifications were ideal.

In 1957 Semmelman (188) published a report of a method for examining porosity in porcelain. He utilised a microscope with a filar head and a 200 x magnification to examine porosity in ground and polished samples of fired dental porcelain. By this time better methods of grinding and polishing the specimen had been developed, and the high power magnification, with its very small depth of sharp focus, enabled the porcelain specimen to be examined in one plane, even though it is translucent.

X-Ray Examination

Klaffenbach (133) found this method to be of little value in the study of structure or density. All that was accomplished, he said, was the detection of an occasional gross defect such as a fracture. This method has accordingly never been popular, and is rarely even mentioned in the literature.

Hardness and Abrasion

Writing in 1936, Felcher stated that in hardness dental porcelains register approximately 7 on a scale in which diamond has a value 10. Porcelain is hard enough to scratch plate glass.

Klaffenbach (133) stated in 1939 that since the Brinell hardness test is dependent on the pressing of a hardened steel ball into the surface of the specimen under a known load and calculating the load and the area of the impression, it was not applicable to porcelain testing. However other sources have apparently succeeded in applying this test to porcelain.

Roche (161) quotes the result of the Brinell hardness test as follows:

Tooth enamel	267
Porcelain	415

Peyton et al (235) give the following figures in 1960 for both Brinell and Knoop hardness tests:

	K.H.N.	B.H.N.
Porcelain	460	405
Enamel	343	300
Dentine	68	48
Plastic	20	15

Porcelain offers considerable resistance to abrasion due to its hardness, but this may be a disadvantage where it contacts opposing natural teeth. Even when the glaze is removed the surface does not wear as much as the neighbouring teeth. This they say may result in excessive wear of the teeth in the opposing arch, or excessive forces exerted during biting which are damaging to both the restoration and to the tissues which support the teeth.

Semmelman (250), writing in 1962 says that at present we have no standard abrasion test for porcelain or for porcelain teeth. Any dental abrasion test development is expected to be complicated by diet effects. Certain foods are extremely abrasive, while others are capable of clogging or reducing the abrasiveness of opposing surfaces, and still others are believed to be capable of cleaning or restoring the abrasiveness. As a significant test is developed, the application will be to reduce the abrasive qualities of porcelain on natural enamel. So called "soft" porcelains he says are usually characterised by low fusion, and may feel soft on grinding due to a melting and flow of the low melting flux phase. Possible relationship to abrasion resistance is dubious but will be investigaged. Relative abrasiveness of homogeneous and heterogeneous porcelains is to be checked, as heterogeneous porcelains may abrade by entire crystals in such a way as to produce rougher abrasive surfaces.

The whole question of the maintenance of satisfactory occlusion is a complex one, especially when restorative materials differing considerably in hardness, surface texture, and abrasiveness are employed.

Specific Gravity

Hodson (203) found the true specific gravity of dental porcelain powders to be approximately 2.4 for medium and low fusing porcelains and approximately 2.6 for high fusing porcelain. After firing the true specific gravity of all the porcelains was about 2.4, and the apparent specific gravity about 2.3. She concluded that the medium and low fusing porcelains were fritted and that most of the chemical reactions were already completed in the preparation of the frit - hence there was little change in the true specific gravity on firing.

Peyton et al (235) agree with the figure of approximately 2.4 for the true specific gravity and give the apparent specific gravity as 2.2 - 2.3 which is very close to Hodson's figure. They found little variation in specific gravity between different brands of porcelain.

Solubility

Sacchi and Paffenbarger (196) tested the solubility of fused dental porcelain in 4% acetic acid. Two tests of each sample were made. Each porcelain was powdered in the diamond mortar, and only that portion which would pass a No.200 sieve was used. A two gramme sample of this powdered fused porcelain was boiled for 30 minutes in 200 ml. of 4% acetic acid. The mixture was passed through a tiered porcelain filter which was then placed in a furnace at 150°C (292°F) for one hour, cooled in a desiccator, and weighed. There are slight differences in the solubility of different porcelains, but none of the materials tested showed sufficient to have any clinical significance.

Semmelman (250) states that particularly in the manufacture of low temperature porcelains, stains, and glazes, the possibility of water solubility must be investigaged. A sample for test is made up of 3 grammes of fused porcelain teeth which are dried to constant weight and then boiled in a water reflux for one week. After boiling the samples are again brought to constant weight and the loss in weight determined due to solubility.

There would appear to be need for a standardised method of testing solubility, even though it appears to be too slight to be of clinical significance.

Compressive Strength

Porcelain jacket crowns generally fail through impact, hence the compressive strength test is probably of no great significance. Sacchi and Paffenbarger (196) carried out tests in 1957 using specimens 7 ∓ 1.5 mm. in height and 4 ∓ 0.7 mm. in diameter. They obtained identical results of 48,000 psi. for Apco low fusing porcelain and S.S.White high fusing porcelain, from an average of five specimens for each test.

Klaffenbach (252) stated that vacuum firing increased compressive strength by 29.2%.

Transverse Strength

Fitzgerald (143) reported in 1936 that the modulus of rupture of high, medium, and low fusing porcelains was very similar.

Sayre (138) writing in 1944 says it is difficult or virtually impossible to observe and measure accurately the forces acting during mastication. He says the test which most closely approximates these forces is the modulus of rupture test. This is made to determine the force in pounds necessary to fracture a transverse section of a material and is used principally in testing brick, tile, terra cotta, and glass. It combines shearing stress, compressive stress, and tensile stress all in one operation. Sayre used specimens measuring only 5 x 5 x 31 mm. before firing. These specimens are so small that the accuracy of his tests is extremely doubtful.

Seth (163) reported the modulus of rupture of dental porcelain to be 7100-8300 psi. This was in 1948.

Hodson (203) in 1959 tested a number of porcelains for transverse strength. Twenty-four fired samples were made of each porcelain, and the shape and dimensions of these were chosen specifically for testing transverse strength. A rubber mould was used to produce bars of condensed porcelain measuring 3/16 inch x 3/16 inch x 1½ inches. The mould was placed on a dental vibrator to compact the porcelain while the excess water was removed with absorbent paper. Vibration was continued until a sheen appeared over the surface of the porcelain. The time of pouring was consistent at six minutes for each bar.

Six bars were produced in the bisque, the glazed, and in the overfired condition for each porcelain. The tray and samples were preheated and placed into the hot furnace at 500°F below the final temperature. The rate of firing was 50°F per minute to the medium biscuit or glaze temperature, and a holding time was used at the glaze temperature to produce the overfired bars. The bars and tray together were cooled to room temperature under a pyrex dish.

The bars were broken in a Tinius Olsen testing machine to determine transverse strength. Procedures described by Andrews (221) were followed in each test and formulae were obtained from him. Individual values for transverse strength that exceeded the average by ∓ 15% were rejected and new averages determined. Transverse strength was measured at the breaking point of the bars under a force applied at the rate of 13 pounds per minute. The bars broke with the curved or conchoidal fracture that is typical of glass. Removal of surface glaze reduced strength in the high and low fusing porcelains, but had no effect on the third. Hodson said that further study is needed to determine whether grinding the surface of finished dental restorations would measurably affect their strength. Although the porcelain with the greatest porosity had the least strength, the porcelain of greatest density was not as strong as the intermediate porcelain. This is shown in the following comparison of glaze fired porcelains (atmospheric firing).

High fusing porcelain	8290 psi.	5.9% porosity
Medium fusing porcelain	9164 psi.	4.3% porosity
Low fusing porcelain	8887 psi.	1.5% porosity

Hodson says that consideration of the many factors involved in testing glass indicated that a variation of 1000 psi. did not necessarily denote a material that was either inferior or superior to other porcelains. Generally it was found that the vitreous porcelains were similar in strength as well as structure.

I feel that Hodson is unwise to try to relate transverse strength to percentage porosity, as this is not the only variable concerned.

Semmelman (250) performs the flexural strength test as follows. A cylindircal bar sample is moulded which measures 2.7 inches in length and 0.31 inches in diameter in the biscuit form. After fusion the sample is tested in the flexure attachment on a Tinius Olsen universal testing machine. A span of two inches is used with central loading and a constant testing speed of 0.015 inches per minute. The half pound sensitivity scale is used on this machine and the breaking point is reported in pounds. The average breaking strain in pounds is then converted to modulus of rupture (pounds per square inch) using average dimensions measured at the break point and the formula shown below. Ten to twelve samples constitute a test series.

$$\text{Modulus of rupture} = \frac{2 \times \text{breaking load} \times \text{span}}{11 \times \text{width} \times (\text{depth})^2}$$

He says that in conclusion, it is difficult to fix a minimum or desirable flexural strength value without consideration of the exact application. Generally speaking we would seldom consider materials below 1800 psi., and feel there is little practical necessity for materials stronger than 2700 psi. On the other hand, in special instances where strength is a problem to a greater or lesser extent, these general requirements would certainly be subject to variation.

The results of Hodson and Seth are fairly similar, but do not resemble the range quoted by Semmelman. One must conclude that either the testing methods are vastly different or, more likely, the method of calculating the final figure is different.

Impact Strength

Klaffenbach (133) stated in 1939 that methods of testing impact resistance were still in an experimental stage. It is known, he said, that a relation exists between tensile strength and impact resistance, but a definite correlation still remained to be determined.

Roche (161) in 1949 said that some confusion seemed to exist as to what is the best method of measuring impact strength, and that different methods appeared to give widely varying results. There can be no doubt he said that acrylic resin has a very much higher impact strength coefficient than porcelain in thin sections. Roche said that the failure to resist an impact in the case of porcelain is not one which need concern porcelain workers unduly because an impact or blow is not a common occurrence, and it should not be confused with the broken jacket arising from masticatory stress. I would take issue with this last statement. A jacket may fracture due to the unexpected encounter of a small piece of bone etc. while the patient is chewing vigorously, and this would constitute failure due to impact in my opinion.

Klaffenbach (252) stated in 1955 that vacuum firing increases impact strength by 48.8% while Peyton et al (235) quote a figure of 50%.

Fox, Kulp, and Lee (214) in 1961 wrote that various impact tests from other fields were found to be unrelated to the clinical behavior of dental porcelain. A test was developed which correlated qualitatively with observed clinical behavior. It was based upon a weight falling from increasing elevations upon a symmetrically shaped porcelain specimen. Representative impact forces necessary for breakage included:

early opaque porcelain	280 gm./cm.
translucent enamel porcelain (air fired)	245 " "
translucent enamel porcelain (vacuum fired)	420 " "
translucent dentine porcelain (vacuum fired)	490 " "

The authors state that in 1954 P.W. Lee discovered that special geometric porcelain forms used in conjunction with a dropping weight test showed distinctions between porcelains that could be related to their clinical behavior.

Work carried out by Vines, Semmelman, Lee, and Fonvielle (212) in 1958 on porcelain densification predicted a stronger porcelain under impact forces, and this was another reason for development of such a test. A weight of known hardness is dropped down a vertical chute onto the specimen. Several geometric specimen shapes were considered, but the two finally selected for study corresponded approximately to an incisal contour and a cuspal contour. These conical forms were chosen as an approximation of incisal and cuspal configurations and because they could be duplicated repeatedly with mechanical accuracy. Since the brittleness of the specimen could be affected by temperature, all specimens were preconditioned and tested at $75 \mp 5^{\circ}F$.

Preliminary investigations showed dental porcelain to be subject to minimum fatigue effects, so impacting was done at heights well below the fracture point. One blow was delivered at each height, successive heights being increased by 1 cm. increments. Failure was determined by the initial sign of fracture regardless of its extent. Since energy measurements are difficult to make accurately under impact conditions, such calculations were eliminated as the height of fall was usually sufficient to differentiate between porcelains. When using different impacting weights, measurements were reduced to units of force expressed as gramme/centimetres for direct comparison. The greater density of vacuum fired porcelain yielded a higher impact strength than air fired porcelain. Increases due to this higher density varied from 50 to 117% by the incisal shaped specimen using the 17.5 gm. impacting weight, which had a Rockwell hardness of 42 C.

There was a corresponding difference in the severity of the type of fracture, as air fired specimens were usually shattered, while the average vacuum fired specimen suffered only minor chipping. A recent field report on laboratory-made jacket crowns corroborates the above data for, on some 8000 jacket crowns made by both the air and vacuum firing techniques, the remakes necessary due to service breakage were: air fired 5%, vacuum 1%.

It would not be wise to draw more than general conclusions regarding this last statement, as too many variables would be present.

Davis, Troxell, and Wiskocil (248) stated in 1955 that each type of impact test has its own particular area of use, and thus its value lies in its connection with field service performance. Data obtained by the present test method (incisal shape, 17.5 gm. weight) show that air fired translucent porcelains are more brittle than air fired opaque porcelains, and that vacuum fired porcelains are less brittle than either. This agrees with field service records. Air fired translucent porcelain was more brittle than the earlier opaque porcelain, which was also air fired. The translucent air fired porcelains apparently were accepted because of their better appearance in spite of their brittleness.

Kulp, Lee, and Fox (214) concluded that vacuum fired porcelains were consistently stronger than air fired porcelains when measured by this test method.

IMPACT RESISTANCE OF PORCELAIN IN GRAMME/CENTIMETRES

Conditions of Test	Air fired translucent enamel	Vac.fired translucent enamel	Vac.fired translucent dentine	Air fired opaque
A	225	420	490	280
B	135	210	245	175
C	281	438	473	434
D	351	402	450	376

Key: A.Incisal shape, 17.5 gm. tup, Rockwell hardness 12C.
B.Incisal shape, 25 gm. tup, Rockwell hardness 42C.
C.Cuspal shape, 17.5 gm. tup, Rockwell hardness 12C.
D.Cuspal shape, 25 gm. tup, Rockwell hardness 42C.

Semmelman (250) says that this test has shown consistent differences in dental porcelains, and can be made to reflect any desired degree of difference by modification of the specimen shape and/or the weight and hardness of the impacting metal part.

To minimise the effects of the heterogeneous nature of the porcelain, ten to twenty samples should constitute a test series. A sample to be tested is placed in the metal fixture so that its tip is exposed. The entire fixture is then located accurately under a vertical calibrated metal chute. He says the starting point has been measured from the tip of the longer specimen, so that the calibrated distances are slightly inaccurate for the shorter specimens.

Semmelman considers that the test is correct in principle, although the degree of difference may have been exaggerated. This is something that only time and further clinical correlation can establish with greater accuracy. With the present set of test variables, vacuum firing produces a demonstrable advantage of 50% improvement in impact strength. Additional clinical experience will be necessary to determine if the test variables should be further adjusted to reflect a greater or lesser degree of improvement.

To sum up, vacuum firing produces an increase of approximately 50% in impact strength over air firing.

Porosity

Pettrow (218) states that inasmuch as porosity constitutes a weakening factor, it is reasonable to conclude that elimination of porosity promotes increased strength. Various commerical dental laboratories estimated gross percentage of breakage at 2 to 7% in air fired porcelain and 0.5% or less in vacuum fired porcelain. Since porosity is only one of the possible adverse variables in a restoration, it is notable that the elimination of this factor alone exercises a marked influence on strength.

Hodson (203) gives the following results for air firing:-

Volume of closed pores as percentage of fired bar

	High	Medium	Low
Bisque	4.55	6.07	0.85
Glaze	5.91	4.34	1.48
Overfired	10.74	6.12	2.53

In 1957 Semmelman (188) criticised gravimetric techniques for the estimation of porosity in dental porcelain. He considered they were laborious and of relatively low accuracy. The effects of metal oxide pigments and firing cause variations in specific gravity of such magnitude as to almost obscure those due to porosity. For example, an air fired porcelain may vary in specific gravity from 2.268 to 2.324 depending upon shade and firing. Similarly, a dense porcelain will vary from 2.370 to 2.425. Such extraneous influences render specific gravity a very inconsistent and unreliable measure of porosity, he says.

Percentage porosity, which compares porous volume with total volume, and requires four weighings and two picnometer measurements to determine the apparent specific gravity of the whole specimen and the true specific gravity of the material from the same article after it has been reduced to a fine powder, is more appropriate. Such a method, he says, is truly indicative of the bubble concentration, but it is laborious, time consuming, and subject to gross errors, as minor variations in any of the four weighings are magnified in dividing nearly equal large numbers.

Semmelman's method involves grinding the surface of the porcelain and then polishing and observing it under magnification. He claims that one glance is sufficient to estimate the porosity, but it is a simple operation to count the visible bubbles and calculate accurately the number per square mm. If the microscope of a Knoop hardness tester is used (200 x magnification), the filar head permits measurement of bubble size, and from this the calculation of bubble volume and percent porosity.

In a good quality air fired porcelain he found there were 74 bubbles per square millimetre, the largest bubble being 0.056 mm. in diameter, and the voids occupying 4.5% of the total area.

In an average vacuum fired porcelain prepared in the same manner, there were 8 bubbles per square millimetre, the largest being only 0.022* mm. in diameter, and the

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* In Semmelman's paper this figure is given as 0.22 mm. but is apparently in error.

porosity being less than 0.1%. Semmelman supplies details of the grinding and polishing techniques used in preparing the specimens, but there is no point in reproducing them here.

$$\% \text{ Porosity} = 100 \times N \times \pi R^2$$

where N is the average number of bubbles per sq.mm.

R is the radius of the average bubble

It has been found advantageous, he says, not to count specks which are so small they cannot be easily and positively identified as bubbles by their round shape. Under 200 power this imposes a practical lower limit for measurement of approximately 0.0001 mm. In each of the ten fields, the largest single bubble is also measured for diameter. The diameters of the ten largest bubbles are averaged, yielding a figure called "average maximum bubble diameter". With the arbitrary assignment of zero value to the smallest bubble, this figure is divided by two to obtain an "average bubble diameter". This in turn gives the "radius of the average bubble". These figures permit calculation of the average bubble area and percentage porosity.

Semmelman concludes that since this is the porosity of a random plane, the area porosity may be considered representative of volume porosity. The results are summarised in the table following, the ranges of maximum and minimum readings being shown in brackets below the averages. In general, the ranges shown are felt to indicate fair consistency, both for the test method and the products.

MICROSCOPIC POROSITY MEASUREMENTS OF DENTAL PORCELAIN

	Air Fired	Vacuum Fired
Ave.no.of bubbles per sq.mm.	73.7 (62.8 - 83.5)	8.1 (6.5 - 11.7)
Ave.maximum diameter	0.055 mm. (0.050 - 0.064)	0.022 mm. (0.018 - 0.025)
Porosity	4.5% (3 - 6.3)	0.08% (0.05 - 0.11)

Semmelman claims the following advantages for his test method:-

(1) Porosity is measured directly and quantitatively in terms of bubble size. Air fired porcelain is seen to have more than 60 times the porosity of vacuum fired porcelain.

(2) Texture effects are indicated directly and quantitatively in terms of bubble size. Air fired porcelain is seen to have bubbles six times larger in area and 2.5 times greater in diameter than vacuum fired porcelain.

(3) The method is unaffected by shade or form, can be performed on commercial articles, and is rapid, accurate, and reproducible.

He states (250) that the method has certain weaknesses, particularly when the bubbles approach the range of minimum visibility, or when the distribution of bubble sizes is not random and normal. However, for most purposes the method has value and utility.

One should not try to compare numerical results obtained by Semmelman's method with those obtained by other methods, as calculations are entirely different. Nevertheless the method appears to be a quick and accurate means of comparing the degree of porosity of different samples of fired dental porcelain. One of its outstanding advantages is that the test can be performed on finished restorations, porcelain teeth etc., unlike other methods which require specially prepared samples.

Fluorescence

A body or material may be said to be fluorescent if it emits radiant energy in the form of light when excited by an independent light source. The wave length of the emitted light usually is longer than that from the independent source. Light of short wave lengths from the primary source, such as blue or ultraviolet, produces fluorescent light that is in the visible range.

According to Radley and Grant (182) "the teeth of a normal person fluoresce intensely white and show the strongest fluorescence of any external organ, but in an old person, or when the teeth are defective, the fluorescence is often reddish."

Dental porcelain to which a fluorescent ingredient has been added will similarly emit light when exposed to the action of ultraviolet rays. Klaffenback (165) concluded "This property of fluorescence, being an inherent quality common to all natural vital teeth, it is of definite aesthetic value to have all dental porcelain restorations including porcelain jacket crowns possess this fluorescence so they will more nearly simulate the shades of the natural teeth in day-light or artificial illumination".

No mention of quantitative tests for this property is made in the literature, but certain manufacturers claim that their dental porcelains and denture teeth fluoresce similarly to natural teeth. Also, one of the cementing media used in the placement of porcelain jacket crowns, S.S. White Kryptex Improved, a silicate cement, is claimed to possess this property.

Coefficient of Thermal Expansion

This physical property can be considered from two angles as regards its application.

(1) The relationship between the coefficients of thermal expansion of dental porcelain and of tooth structure, and the effect of this relationship on marginal penetration around the completed restoration.

(2) The relationship between the coefficients of thermal expansion of various dental porcelains and metals, and the effect of this relationship on the formation and physical properties of the restoration as a whole.

Skinner (178 page 27) gives the following results for average expansion coefficients in the range 20° to 50°C.

Material	Linear Expansion Coefficient ($\times 10^{-6}/$ °C
Tooth (across crown)	11.4
Silicate cement	7.5
Amalgam	25.0
Acrylic resin	81.0
Porcelain	4.1
Platinum	9.0
Gold	14.4

The above figures should only be regarded as approximate. Nelsen, Wolcott, and Paffenbarger (206) have demonstrated that the coefficient of thermal expansion of a restorative material has a direct bearing upon the fluid exchange at the margins of dental restorations that occurs with a change of temperature in the mouth when hot and cold foods are eaten. While the coefficient of porcelain is not as close to that of tooth structure as is that of gold (on the above figures), the porcelain jacket crown appears to give adequate clinical results in this regard.

Sacchi and Paffenbarger (196) tested the coefficients of thermal expansion of two dental porcelains by an automatically recording interferometric method in 1957, and their results are as follows (Range 30-400°C).

Porcelain	Linear Expansion Coefficient ($x\ 10^{-6}/\ {}^{o}C$)
Apco low fusing	7.8
S.S.White high fusing	6.4

They concluded that certainly no significant strain could be set up in the crown during cooling that could be attributed to the small differences in the coefficients of thermal expansion among the porcelains they used.

Semmelman (250) states that thermal expansion measurements are required in the development of low expansion porcelains for use in tooth products with extremely high grindability, and for the control of production operations involving prestressing between two or more porcelain components, or between porcelain and metal components. Two types of test are used, one with a dilatometer and the other with an interferometer. In certain types of studies the expansion at a certain temperature may be all the information that is desired. For example, in studying the compatibility of enamel and dentine porcelain of a basic feldspathic composition, the differences in coefficient of expansion at

$800^{\circ}C$ have been established as being critical by practical relation to such physical phenomena as thermal shock resistance.

On the other hand, with different porcelain compositions a different softening point will result in some other temperature being critical. In certain types of compositions the thermal stability of the porcelain may be forecast from the inversions marked by "humps" in the thermal expansion curve at relatively low temperatures. In such cases it is customary, he says, to subject the porcelain samples to several refiring cycles as might be done in staining or glazing, remeasuring the thermal expansion after each such refiring. Instability will be noted by growth of characteristic "humps" which identify the crystalline phase being formed.

Thermal Shock Resistance

Semmelman (250) states that further work is being done to evolve a suitable test for this property. Feldspathic porcelains show initial thermal shock failure between 110° and $180^{\circ}C$, depending upon several factors, one of which is thermal expansion. This is sufficient for careful laboratory operations, but cannot be considered trouble free. Porcelains have been made with as much as $500^{\circ}C$ thermal shock resistance. On a practical basis however, it appears there is little necessity for more than $250^{\circ}C$ shock resistance.

Porcelain VS. Acrylic Resin

Roche (161) says the thermoplastic resin methyl methacrylate, usually called "acrylic", was first used as a denture base in 1933 when it was introduced to the profession by I.C.I., and marketed under the name "Kallodent" in the form of polymerised cakes, which were injected under heat into a mould. Credit is usually given to a German scientist Kulzer for the first powder-liquid acrylic, and whose patent was taken up by the firm Paladon.

Substitution of the pink denture base dyes and pigments by the ivory and yellow colours enabled the material to be first used in 1937 for the fabrication of artificial teeth, crowns, and bridges.

Seth (163) states that like porcelain, acrylic resin is a non-conductor of heat and electricity, but softens at 160-180°F and scorches readily in a naked flame. It is resistant to oral fluids (only to a degree) and impervious to bacteria, but undergoes slight dimensional change in water due to imbibition, and to various degrees is affected by medicaments and solvents containing chloroform, acetone, alcohol, phenol, and essential oils such as eugenol, which are used in everyday dentistry. Acrylic is translucent and has no taste or odour. In my opinion it does have some slight taste or odour, much of which depends on whether polymerisation was completed in the curing process.

Acrylic is radiolucent, so that an all-acrylic jacket crown would be extremely difficult to detect if inhaled into a bronchus or lung. Opacifiers can be added to overcome this deficiency, but up to the present time these have only been added to denture base resins.

Roche (161) says that the surface finish is under better control in the case of an acrylic jacket crown, but that this advantage is quickly lost as the original polish is removed by the abrasive action of food or toothbrushing. The brilliance may be restored by polishing, but it is only done at the expense of the material. From these considerations it would seem that the porcelain jacket crown has the advantage aesthetically over its acrylic counterpart in the long run.

Seth (163) gives a comparison of some of the physical properties of the two materials in tabular form:

	Porcelain	Acrylic Resin
Specific gravity	2.3 - 2.32	1.18 - 1.19
B.H.N.	415	18 - 22
Modulus of Rupture	7100 - 8300 psi.	10980 psi.
Coefficient of thermal expansion (20-50°C)	4.1×10^{-6}	81×10^{-6}

Tylman and Peyton (175) state that while the acrylic resins have been found to possess as a group the highest scratch resistance of all synthetic resins, they remain very low in comparison with the hardness of other restorative materials such as amalgam alloy, or silicate cements, and far below dental enamel. They also state that no variation in polymerising techniques can bring about an improvement in the hardness of the material.

Roche (161) says that where the material occludes with a sharp incisal edge of a natural tooth, an indentation of the acrylic will be found, which may progress to an actual hole in the case of an acrylic jacket.

Osborne (177) carried out transverse loading tests which showed that at a temperature of 60°C polymerised acrylic resin softened, while porcelain did not. As the temperature rose to 70°C, there was a quick fall in transverse strength and the material bent easily. As many people eat and drink foods at these temperatures, it would be possible for an acrylic jacket to soften and bend under masticatory stress. Skinner (178) reported that there was also some degree of flow at lower temperatures.

Tylman and Peyton (175) state that the elastic distortion may be sufficient to break the cement seal in a restoration. Roche (161) says that this feature is particularly apparent in upper incisor acrylic jacket crowns where the degree of overbite is such as to cause an impingement of the lower incisors on the incisal half of the jacket. The leverage may produce a lifting at the lingual shoulder of the jacket as the material is stressed beyond its elastic limit. This lifting of the lingual shoulder margin may be sufficient to break the cement seal and permit an ingress of bacteria or food particles.

The difference in coefficients of thermal expansion between tooth structure (11.4×10^{-6}) and acrylic resin (81×10^{-6}) may be sufficient to break the cement seal without the added influence of the above factors.

Attempts have been made to overcome this problem of fracture of the cement seal by interposing a thin coping over which the acrylic crown is processed. Gold has often been used for this purpose, but Porteous and Vondran (141) suggested the use of a coping of fused porcelain which did have an aesthetic advantage over the gold. Even when such methods succeed in safeguarding the cement seal, the other problems of softness and flow of the acrylic remain. For this reason, acrylic resin must be considered unsuitable for the fabrication of any type of permanent crown where it forms the entire outer surface. However, it is a very suitable material for temporary crowns, where its excellent temporary aesthetics, ease of fabrication and alteration in the case of cold cure acrylic, and its high impact strength show to advantage.

<u>Tissue Tolerance</u>

Bastian (35), Le Gro (45), Howard (90), Grubb (140), Seth (163), Roche (161) and many other clinicians have reported on the favourable reaction of gingival tissue when contacted by a properly glazed and contoured porcelain restoration.

Allison (274) demonstrated this by constructing a number of bridges for Rhesus monkeys utilising pontics with either fused porcelain or acrylic resin in contact with the underlying ridge mucosa. After three months with the bridges in situ, the monkeys were sacrificed and sections of the ridge underlying the pontics were made. The tissue beneath the acrylic resin pontics showed extensive inflammatory changes. There was little or no change from normal in the tissues beneath the fused porcelain pontics.

Pini (275) obtained his material by means of biopsy from the human mouth. He obtained a series of specimens from the gingival mucosa taking care to include the area contacting the prosthesis. He was thus able to study the reactions of the gingivae to the different materials used. His observations were as follows:-

"Beneath acrylic resin pontics the corium shows the features of either a subacute or chronic inflammation with both a consequent increase in the collagenous fibres, and the appearance of lymphoplasmocytes and histiocytes around the vessels, which have often increased in number. The epithelium is often thickened, and the basal cells in some regions show a tendency to range themselves into several rows. The prickle cells also range themselves into several layers taking different aspects; some of them are swollen, others are smaller with a well shaped nucleus, and others are definitely elongated and their intercellular borders are generally well visible. The epithelium usually shows proliferation which occurs at the mesenchymal aspect through the presence of thin papillae which go deep into the corium and simulate acanthosis."

Pini found that reactions to fused porcelain are comparatively mild, and eventually show a trend towards sclerosis.

He also investigated the effects of two metals, gold and stainless steel, in contact with the ridge and his findings regarding these two materials are included for purposes of comparison.

Stainless steel provoked a necrotic tendency in addition to the histologic phenomena associated with acrylic resin. In addition, effusions of red corpuscles were present both in the corium and in the core of the epithelial structure, which became disintegrated.

With gold alloys on the other hand, Pini found that epithelial proliferation was less evident, while collagenous and sclero-hyaline fibres were found in the corium. The characteristic reaction is one of sclerosis.

From the foregoing studies one may conclude that glazed porcelain is very well tolerated by the mucosal tissues. A highly polished gold alloy, while not as satisfactory, is nevertheless adequate. Acrylic resin and stainless steel are definitely contraindicated when they are intended to remain in contact with the gingival tissues for long periods.

FIELD OF APPLICATION OF THE PORCELAIN JACKET CROWN

In 1915 Avary (15) outlined what in his opinion was the field of application for the porcelain jacket crown, and it is interesting to recall his views:-

"Porcelain jacket crowns are indicated in the following cases: peg laterals, malformed or discoloured teeth, where a tooth is over one-third broken down, badly eroded teeth, deciduous teeth that may remain in the adult mouth (radiograph case and ascertain that there is not an unerupted tooth under the deciduous tooth). Jacket crowns may also be used to advantage when opening the bite. All gold crowns that irritate the gums should be replaced with porcelain jacket crowns. Anterior teeth that are rotated may be corrected by jacketing.

The jacket is the ideal crown for several reasons. It is not necessary to devitalise the pulp, except in cases in which the pulp was exposed at the commencement of the operation. It is the most natural looking crown and it possesses the greatest degree of translucency. Also, detail individualities may be reproduced in jacket crowns to correspond to the natural teeth.

The porcelain jacket crown has a tendency to prevent the recurrence of caries, as the entire crown of the tooth is re-enamelled with porcelain and it does not irritate the gum. And since the radiograph has come into general use in dentistry, we realise more than ever the importance of preserving the vitality of the teeth wherever possible, as so much trouble can be traced to improperly filled root canals."

In addition, Le Gro (45) suggested that "any central or lateral incisor or cuspid showing caries involving both approximal angles, or a single angle, either mandibular or maxillary, in an otherwise perfect denture, is a case suitable for a porcelain jacket." This statement was supported by Bastian (115), who also mentioned the use of the porcelain jacket crown as a bridge abutment.

Mallory (84) listed some contra-indications -

(1) Where the root cannot be properly prepared.

(2) Where some other type of restoration can be made more easily and will not show.

(3) Where no space can be obtained for bulk, as porcelain must have certain bulk for strength.

He considered that porcelain jacket crowns could be used on any tooth in the mouth, but thought it best to limit them to the premolar and anterior teeth, except for a very occasional molar. There are many restorations for the posterior part of the mouth just as efficient, and much easier made, he said, but in certain places where appearance is all-important, there is nothing to take the place of this ideal. Howard (39) believed there were comparatively few cases where a porcelain jacket crown was indicated on a vital molar tooth. If a vital molar was completely encircled by caries and there had been considerable pulp recession, he considered this to be a suitable case. In the case of pulpless molar teeth, he considered the porcelain jacket crown to be an ideal restoration when placed over a cast metal core with pins cemented into the root canals. Breakage was not a problem he said, providing that the preparation had been properly carried out, the crown was an accurate fit, and the porcelain of uniform thickness.

Oppice (62) considered that in the teeth of most patients under eighteen years of age, pulp protection would not have been built up, and therefore a radical preparation of jacket crown type would not be indicated. Clark (127), on the other hand, considered that the porcelain jacket crown may be successfully used on relatively young patients (from 14 years of age). He recalled some thirty eight patients for whom he had constructed porcelain jacket crowns some eighteen years previously.

6 of the crowns were on patients then 14 years of age.
16 " " " " " " " 15 " " "
16 " " " " " " " 16-20 years of age.

He found all of the teeth to be normal clinically, and only one was found to be non vital. This particular case he ascribed to cutting the distal surface of the tooth too deeply during the original preparation.

Saklad (244) published details of a series of clinical cases involving the use of porcelain jacket crowns. The series was interesting in that it illustrated the wide field of application for the use of porcelain jacket crowns in correcting deformities of the anterior teeth.

The porcelain jacket crown was developed over sixty years ago, and during that time no other type of crown has been developed which surpasses it in aesthetics. In my opinion, the all-porcelain jacket crown is still the permanent restoration of choice where full coverage is desired on either the upper or lower anterior teeth or premolars.

However, occlusion must be favourable, and it must be possible to prepare the tooth to such a shape as to permit the construction of a well-supported crown of fairly even thickness. This latter condition also applies to pulpless teeth. Where the occlusion is not favourable, or where it is anticipated that the tooth may be required later to act as an abutment for a partial denture, it is more prudent to consider alternative types of crown, since porcelain may fracture as a result of uneven loading. Also, adequate rest seats for clasps are difficult to prepare in the surface of a porcelain jacket crown without weakening it. Of course a porcelain jacket can always be deliberately fractured off by splitting and replaced by a different type of restoration should this be subsequently desired as the result of loss of other teeth.

Composite porcelain-metal crowns, such as the newer porcelain fused to precious metal, are preferable for restoring molar teeth, as they are stronger and require, in most cases, less occlusal reduction of the tooth. They are also preferable for cases where an unfavourable occlusion produces heavy stress loading, and where it is not possible to provide adequate thickness for an all-porcelain crown. They make more suitable abutment restorations for both fixed and removable partial dentures. However their use requires some sacrifice in aesthetics, as even when it is not necessary to have the metal project through the porcelain to a visible surface, the metal substructure still produces a shadowy appearance which lessens the translucency of the restoration, unless considerable tooth structure is sacrificed.

EXAMINATION, DIAGNOSIS, AND TREATMENT PLANNING

Le Gro (54) in 1925 emphasised the importance of proper examination and diagnosis before undertaking provision of a porcelain jacket crown. He mentioned the use of visual examination, X-rays, visual study of the occlusion, and the use of study models in treatment planning. Le Gro at this time used sectional compound impressions to obtain the study models, and it is likely that they left something to be desired in the matter of accuracy, when compared with those readily obtained by the use of elastic impression materials such as alginate and reversible hydrocolloid. In a later paper (100) in 1927 he stated that X-ray examination was advisable "to determine the size and position of the pulp, and also to detect any pathological conditions that might be present." Mallory (91) advised much the same procedure.

Oppice (62) stated that study models are especially helpful when several jackets are contemplated to relieve unsightly spacing of the anterior teeth. It is wise, he said, to fill these spaces on the plaster model, recarve the teeth, and observe whether the result will be satisfactory.

Sayre (138) suggested in 1944 that in addition, pulp vitality should be electrically and thermally tested, and that accurate study casts will permit a much more detailed examination of the occlusion than is possible in the mouth.

Gill (139) stated that photographs will help immensely in reproducing the highlights and surface anatomy, but I have found them to be of little assistance. He also suggested that in some cases it is advisable to make duplicate study models, using one to cut the preparations, and constructing the restorations in wax. This, he said, is especially helpful when two or more crowns are to be made, and it should provide a more definite idea as to how the preparation should be carried out.

Hagen (160) stated in 1948 that when two or more adjacent teeth are to be prepared, it is advisable to operate on only one tooth at a time. The necessary impression of the tooth and the region should be taken, he says, then a temporary crown should be prepared and placed for interim care before the mesial aspect of the next tooth is reduced. Hagen considers it is practically impossible to reproduce accurately the mesial and distal diameter of the tooth unless this procedure is followed.

When multiple adjacent porcelain jacket crowns are decided upon, I consider it preferable to construct them simultaneously on alternate teeth only. When these have been completed and cemented into place, the remaining teeth are prepared and their crowns constructed and cemented in the same way. In this fashion, each tooth being prepared has adjacent to it either an intact natural tooth or a completed porcelain jacket crown. Thus there is always a proper guide for both the preparation, and the form and contacts of the crowns.

In the past, some clinicians have attempted to prepare a whole group of adjacent upper anterior porcelain jacket crowns simultaneously. This method enables economy of both time and material, but usually produces disastrous aesthetic, and sometimes functional, results. With no adjacent teeth or crowns as a guide, it is difficult to reproduce the previous arch form and tooth morphology and study models are not sufficient help in this regard.

Hagen (160) advises the use of two preoperative diagnostic X-rays of a tooth to be prepared, one a periapical and the other of the crown area only. For the coronal picture, the film is placed about 3 mm. above the lingual gum margin, and the exposure taken straight through the crown, resulting in an accurate picture of the pulp and its extensions. This would appear to be sound practice and a considerable help in planning a suitable preparation. Klaffenbach (165) agrees with Hagen regarding the need for two X-ray pictures of a tooth to receive a porcelain jacket crown restoration, but his second picture is a bitewing film which may include a little more area than the one Hagen suggests. Klaffenbach claims the bitewing film determines the size and position of the pulp and pulp horns, the relationship of fillings or caries to the pulp, the crest of the alveolar process, alveolar recession, and gingival relationship with adjacent teeth. If the picture is to show the outline of the gingiva, it will need to be slightly under exposed as compared to the periapical film. Klaffenbach advised studying the occlusion by mounting the study models in an adjustable articulator.

Ewing (184) suggested that the mobility of the tooth should be tested by digital means, especially during the various occlusal excursions. This can be accomplished, he says, by touching the finger lightly on the labial surface of the tooth while the patient makes the various mandibular excursions. The occlusion should be checked with special emphasis on degree of overbite and overjet. He advised against planning the treatment of any tooth unless there is some degree of normalcy in occlusal relations. In this connection Brecker (261) warns against constructing porcelain jacket crowns for patients who suffer from the habit of bruxism, which he says will produce either excessive wear of the opposing natural teeth, or fracture of the porcelain jacket crowns. He also advises that very young or aged people are not favourable patients for porcelain jacket crown restorations. There is of course a danger that young patients are prone to fracture a porcelain jacket crown playing active sport etc., and for this reason some other type of jacket crown with better impact resistance may be advisable until the patient is a little older.

Bartels (195) carries the process of preoperative occlusal analysis and correction much further than do most authorities. To accomplish this he mounts the study models in an adjustable articulator on the patient's axis-orbital plane, and takes a complete set of centric and eccentric condyle path movement records. He also advocates the routine taking of full mouth X-ray films.

Though this is obviously the method par excellence, one must seriously question whether it is routinely necessary. It would certainly make the provision of a single porcelain jacket crown a very expensive proposition. Each case should be judged on its merits. The patient with a hopelessly locked occlusion which is perfectly adequate for masticatory requirements, and where the supporting structures appear perfectly healthy, is not going to be assisted by an extensive occlusal analysis prior to the construction of one or two porcelain jacket crowns on the upper anterior teeth.

Conversely, other patients may derive enormous benefit from an extensive occlusal analysis and selective grinding prior to operative procedures. Bartels states that correction of imbalance in the various eccentric movements is an important factor in preventing potential fractures to porcelain jacket crowns. This is broadly true, but there are exceptions, as stated above.

Brecker (261) warns against attempting to correct mandibular prognathism by the use of labially inclined upper porcelain jacket crowns, which he says will result in a peculiar appearance, unfavourable leverage, and labio-gingival areas of food stagnation.

He also (170) says that treatment of spaced teeth requires careful planning. Sometimes the covering of one tooth will bring about a pleasing effect, and then there are occasions when it becomes necessary to cut four teeth to improve the aesthetics. A wide diastema between the upper centrals may have been caused by hypertrophied frenal tissue. In some cases multiple spaces exist along with the median diastema. A solitary space may occur between any two teeth and is sometimes due to the retention of deciduous roots, or the genetic absence or removal of a tooth, in which case the remaining teeth have drifted. Spaced teeth caused by periodontal disturbance should not be considered for correction until the condition is resolved and stabilisation restored. In the correction of spaced teeth Brecker stresses the need for careful planning, with study models. He suggests the use of white wax to determine the effect of the completed restoration.

To sum up, a rational procedure for the examination would be as follows:

(1) Visual examination of the patient including the entire dentition, the occlusion, the patient's general appearance, lip line, profile, etc.

(2) Digital examination of the tooth or teeth to be jacketed for mobility during functional mandibular excursions.

(3) Electrical and thermal pulp testing of the teeth to be jacketed.

(4) X-ray examination - full mouth X-rays if indicated or at least two films of each tooth to be jacketed.

(5) Study models, poured in a densite stone for preference. These models, held in the hand, are used in conjunction with visual and digital examination of the occlusion. With the aid of this examination it should be possible to decide whether a full occlusal analysis, followed by selective grinding, is indicated before preparation is begun, or whether only minor adjustments, or no adjustments, are necessary to render the patient's occlusion satisfactory.

(6) It should be decided during the visual and X-ray examinations whether orthodontic treatment is indicated before commencing preparation, in order to move the teeth into a more favourable position.

ORTHODONTIC TREATMENT

Klaffenbach (165) says that for certain cases it is essential that orthodontic treatment precede the restorative procedure. The correct positioning of the tooth to be restored, and the placing of the adjacent or opposing teeth in proper alignment or occlusion with the tooth to be restored, are necessary if a satisfactory result is to be achieved. He gives several examples:

(1) When a space exists between the central incisor teeth and it is desired to close the gap by placing porcelain jacket crowns slightly wider than the natural teeth, these teeth should be so positioned that spaces of equal width are obtained between the central and lateral teeth. This will provide for an equal thickness of porcelain on the mesial and distal of each crown.

(2) When the so-called peg shaped upper lateral tooth is not centred in the space between the central and cuspid tooth mesiodistally or labiolingually, it can generally be favourably positioned with orthodontic treatment.

(3) Klaffenbach suggests that the use of a Hawley bite plate type of orthodontic appliance for certain closed bite cases will frequently provide sufficient vertical opening of the bite for the placement of a porcelain jacket crown with adequate lingual thickness and

favourable occlusal conditions.

(4) He says that orthodontic treatment should always be given due consideration before attempting to correct the alignment of certain rotated teeth by the use of porcelain jacket crowns. Such teeth are frequently deceptive and require more extensive cutting than anticipated. He suggests that where there is any doubt, the preparation should be made on a study cast and the crown built or carved to form with cream coloured inlay wax to ascertain the advisability of correcting the alignment with a porcelain jacket crown.

Nuttall (217) writing ten years later, supported Klaffenbach's recommendations regarding orthodontic treatment.

Brecker (170) says that in the correction of abnormally spaced teeth, orthodontia is the method of choice, but the patient may be too old to be a suitable case. Wonderful results are often obtained, says Brecker, by the use of porcelain jacket crowns. However he says there are times when it is best to do nothing about these abnormal spaces, because an attempt at correction will not live up to the expectations of the patient. In Brecker's opinion, often the perfection the patient desires can be accomplished only with a full denture possessing translucent, perfect artificial teeth! He is being rather cynical, but it is very true with some patients.

Returning to orthodontia, he says assuming that the tooth or teeth can be moved, it must be possible to stabilise them in their new positions. Also, some patients object to the wearing of the necessary appliance.

Having decided that orthodontic treatment is desirable for a particular case, the question is who should undertake it. Moving a tooth mesially or distally to centre it in a space for a patient under twenty five years of age for instance, falls well within the province of the general practitioner who wishes to undertake this section of the treatment himself. Major tooth movement, usually either labially or lingually, in the older patient with denser bone is probably better referred to the orthodontic specialist.

Preparation of the Tooth

Pincus advises (112): "Always treat the gingiva so as to have a normal condition present before making a jacket preparation with its finished gingival shoulder. Many times preparations are made when gingivae are spongy or swollen, due to either subgingival deposits or mild infections, and after the jackets are cemented, the subsequent shrinkage of tissue exposes the porcelain margin, or the bluish appearance of the gingivae subtracts from the effectiveness of the result". It is important to establish and maintain the health of the gingival and periodontal tissues both before and during the preparation, temporary coverage, retraction and impression procedures, and final cementation of the crowns. Healthy gingival tissues will recover promptly from minor injuries, such as accidental bur cuts during the preparation, if they are not too severe. Chronic irritations arising from overextended preparations, poorly fitting temporary crowns, clumsy retraction and impression procedures, and poorly fitting or poorly contoured permanent crowns will result in permanent damage to the gingival tissues, usually manifested by inflammation and recession.

General Considerations

There is an embarrassingly large amount written on the preparation of teeth for porcelain jacket crowns in the literature, much of it contradictory, and most of it empirical.

This position has arisen because the design of the porcelain jacket crown preparation is not a subject which has proved very amenable to basic research so far. Walton and Leven (224) in 1955 attempted to study the design by means of photoelastic stress analysis of plastic replicas of porcelain jacket crowns and their preparations. However, this line of investigation has so far proved to be a rather clumsy research tool, in spite of the intensive work carried out by these two men. The only criteria then, by which we can evaluate efficiency of the design of a porcelain jacket crown preparation, are general engineering principles of static structures, and some knowledge of the physical properties of the materials concerned - not a really satisfactory state of affairs in my view.

Oppice (62), writing in 1934 stated "The superstructure, since it is to be of porcelain, will be friable. There will be an increase in resistance to fracture as the thickness is increased. In all cases we are limited as to thickness outwardly by the appearance and the demands of occlusion. For teeth containing vital pulps, we are limited as to thickness inwardly by the necessity of preserving the pulp."

It has generally been conceded desirable to prepare the tooth with some sort of shoulder chamfer, or finishing line, rather than completely shoulderless.
A finishing line of some sort simplifies the technical pro-

cedures, and in any case it is not possible to accurately finish porcelain to a knife edge while still maintaining its glazed surface.

Le Gro (45-58) is generally given credit for first suggesting the completely shoulderless preparation and crown. He wrote "The shoulderless type of porcelain jacket should have a decidedly important place in our armamentarium. Aside from its adaptation to certain types of dental anatomy, it is most decidedly indicated for teeth of children under sixteen years of age."

In reply to this, it may well be argued that children under sixteen are hardly suitable subjects for a porcelain jacket crown in any case. The large pulp makes adequate tooth reduction, even for a shoulderless preparation, difficult and hazardous, and the level of the epithelial attachment in young patients is such that even if a porcelain jacket crown can be constructed, normal gingival recession will expose the margin of the crown in a few years, and the appearance will be such that a repreparation and remake of the crown will be necessary. Also, young patients are somewhat prone to receive minor impacts on the mouth in playing sport etc. These impacts usually do no more than slightly chip the enamel of the natural teeth, but they may be sufficient to fracture a thin porcelain jacket crown.

All things considered, it is generally wiser policy to provide those young patients with some other type of crown or intracoronal restoration until such time as the pulp and epithelial attachment have receded to a more favourable level. It is not really possible to set an arbitrary minimum age for the provision of a porcelain jacket crown restoration, as pulp size and level of the epithelial attachment are really the deciding factors, but in most cases twenty years of age is fairly safe. A visual and x-ray examination will decide this matter.

Wheeler (66), and most other authors, are against the shoulderless type of all-porcelain jacket crown. Wheeler objects to it chiefly on the grounds that porcelain cannot be finished to a feather edge. Even with the utmost care in finishing, he says, magnification will show a saw edge, and besides being rough, this edge will have small bubbles along it and an intermittent glaze.

Speaking of the shoulderless crown, Avary (36) stated "It gives a false gingival contour and a weak feather edge, which may easily be broken during cementation." Avary considered there was never a tooth in any adult mouth, either peg lateral or lower incisor, in which a small but definite shoulder could not be cut.

Oppice (62) sums up "Experience has taught me the weakness of a feather edge of porcelain and the fact that a small shoulder can be definitely made on any tooth without injury to the pulp. A study was made of ground sections to determine whether any bulge or bell shaped contour could be found in the dentine of the crown. After an examination of hundreds of those sections, it can be said that the bell shape of the crowns of our teeth is found only in the enamel, and never in the dentine. There is no constriction in the dentine at the junction of the crown and the root." He concluded that a shoulder was essential to a good jacket preparation.

The shoulderless preparation does certainly require less tooth reduction, is generally easier and quicker to prepare, and less potentially damaging to the pulp. Bastian (41) attempted to have the best of both worlds by making use of a shoulderless preparation over which was cemented a cast gold ring of roughly triangular cross-section. This gold casting, which followed the gingival contour, provided an artificial shoulder against which a porcelain jacket crown could be finished. The technique was used by Martin (38) in 1924, who used an indirect-direct technique for obtaining a wax pattern for the casting. Bastian waxed the pattern over a strip of platinum foil on a die, and the foil was left in place after the casting was produced, except that it was trimmed flush with the margins of the casting. A conventional type of shoulder porcelain jacket was then fabricated.

When such a restoration is used, the gingival crevice must be fairly deep, if the gold collar is not to show. Also, unless a fair degree of tooth reduction is carried out, the finished crown will be bulky around the cervical region, leading to understimulation of the gingiva and possible food stagnation, especially in the interproximal region. It is difficult to imagine any situation where this type of restoration would have any advantage over an all-porcelain jacket crown constructed over a preparation with a very narrow shoulder, chamfer, or finishing line.

There is no reason why the width of the shoulder should not be varied to suit the particular case. In fact it may be desirable for it to vary in width in different areas on the same tooth. For instance, on an upper first premolar the mesial surface often has a pronounced concavity in the gingival region, and if this is so it is desirable that this region of the tooth be prepared with a very narrow shoulder, chamfer, or finishing line. The rest of the tooth can be prepared with a shoulder of normal width.

A preparation should always be planned in advance by means of the visual and x-ray findings and the use of the study models. A proper assessment of the case will decide if a porcelain jacket crown is the restoration indicated, and if so, how the preparation should best be carried out. The preparation must be planned so that

(1) The health of the pulp, gingival, and periodontal

tissues is safeguarded.

(2) The shape of the preparation is such that it provides for an adequate, fairly even thickness of porcelain which is properly supported by either sound tooth structure, or a combination of sound tooth structure and a hard, strong restorative material such as reinforced amalgam or cast gold. Cement should only be used to fill in small depressions in the preparation, as it does not have sufficient strength for replacing structural deficiencies such as missing corners etc.

Having dealt with shoulders whose width is necessarily limited by the proximity of the pulp, the amount of healthy tooth structure remaining, and the external size and contour of the finished crown, what is the ideal width for the shoulder when the pulp has receded and there is adequate healthy tooth structure with which to work? The literature is most confusing on this subject.

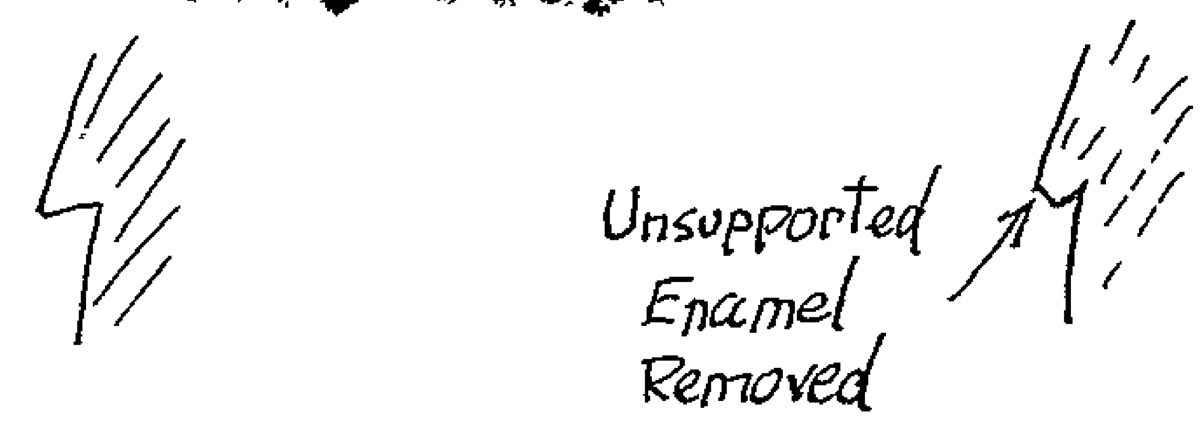
Avery (15) said that "the smallest shoulder than can be trimmed is sufficient, as the strength of a jacket crown does not depend upon the bulk of porcelain, but on the close adaptation of the jacket crown". Not many writers agree with this view. Bean (32), Bastian (115), and others suggest a shoulder 0.5 mm in width as optimal. Tylman (232), Vehe

(82), and Gill (131) suggest 0.75 mm., Argue (80) says 0.5-1.0 mm., and Holland (240) and Klaffenbach (165) advocate 1.0 mm.

Assuming that it can be equally well supported, a slightly thicker crown should be stronger, and its colour more likely to resemble that selected from the shade guide. If the porcelain is too thin, the substructure and cement will influence its shade. As there appears to be no particular advantage to be gained from having a crown thicker than 1.0 mm. in the shoulder region, it would seem reasonable to suggest that the optimum thickness of the porcelain should be 0.75-1.0 mm., and that the shoulder should be so prepared.

Slocum (102) and other writers of that time suggested that the angle between the shoulder and the axial wall of the preparation should be an acute angle in order to lend strength to the crown. In more recent times, Walton and Leven (224) suggested that for an upper anterior tooth, the jacket crown would resist thrusts from the opposing teeth better if an acute angle was employed for the labial part of the shoulder. Presumably in the case of a lower anterior tooth, the acute angle should be on the lingual portion of the shoulder. If the occlusion was such that the upper anterior teeth were lingually placed in relation to the lower teeth, one could assume that conditions would be reversed.

This may have atheoretical mechanical advantage, but in practice there are several difficulties. Firstly, it is difficult and tedious to cut, placed as it is below the free gingival margin. If no enamel is present this is not too great a problem, especially if the acute angle is confined either to the labial or lingual part of the shoulder. If enamel is present, unsupported enamel rods must be trimmed away, and this will remove most of the acute angle, unless the shoulder is cut very deep.



1. Without Enamel Present.   2. With Enamel Present

Secondly, it will be found difficult to subsequently adapt the platinum matrix into this acute angle without tearing the platinum. In short, the advantages are more theoretical than real.

Vehe (98-99) writes "An attenuated, acute angled margin on either the porcelain or the enamel would easily be liable to fracture, and to most safely protect both of these margins it seems logical that right angled margins would give the greatest possible protection to both structures." Oppice (62) and McBean (43) both concluded that the shoulder should be at right angles to the axial surface so as best to resist the forces of occlusion.

There are also somewhat conflicting views on the desirable level of the shoulder in relation to the gingival tissues and their epithelial attachment. Schneider (97) advocated cutting the shoulder "as near as possible to the gum and tooth attachment". Both (96) suggested removal of all enamel so the shoulder could be prepared entirely in dentine.

Thompson (104), Argue (80), Vehe (98-99), and others disagree with these views. Thompson rightly states that in order to take a band impression of the prepared tooth, the band must be forced slightly beyond the shoulder. If the shoulder has been cut in very close proximity to the epithelial attachment, this attachment may be injured during the subsequent retraction and impression procedures, and the result may be an abnormal degree of gingival recession after the crown is placed.

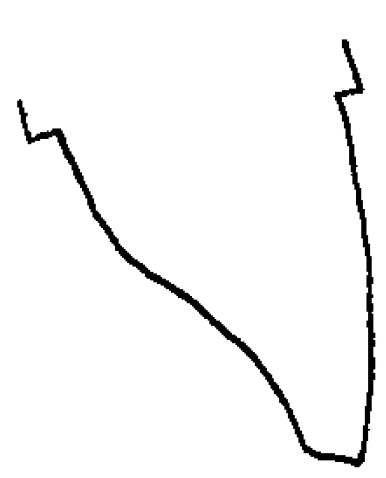
Most writers agree that the shoulder should be placed below the level of the free gingival margin, but how far below depends upon the depth of the gingival sulcus, or in other words, upon the level of the epithelial attachment (63, 64, 65). It is wise to check the depth of the gingival sulcus with a periodontal probe before cutting the shoulder. It is reasonable to conclude that the shoulder should be cut at a level beneath the free margin of the gingiva, but sufficiently above the epithelial attachment so as to permit taking a careful band impression without damaging the attachment.

If this is accepted, then radical methods of gingival retraction prior to the preparation, as advocated by Sykes (105) and Megaw (106), appear to be unnecessary.

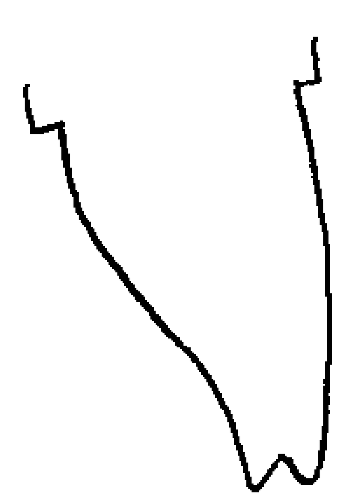
Bartels (216) says that tooth reduction on the labial surface can be minimised by the creation of a labial chamfer instead of a shoulder. It is hard to see any advantage in this, as a porcelain jacket crown which is very thin on the labial surface is weakened somewhat, and also it is more difficult to achieve proper colour values if the porcelain is very thin. Bartels advocates increasing the thickness of the labiogingival area of the crown by about 0.5 mm. to overcome this, but overcontour of the crown in this region is liable to remove the natural stimulation of the gingiva during chewing and lead to a slow deterioration in its health, to say nothing of its effect on aesthetics. Coomer (208) also advocates the use of a chamfer rather than the more conventional shoulder at right angles to the axial surface. The fact that shoulderless porcelain jacket crowns have been mechanically, if not physiologically, successful, rather indicates that the form of the shoulder, or even its complete absence, plays little part in the strength of the completed and cemented restoration.

In reducing the incisal or occlusal surface, Carey (40), Bartels (216), and most other authors suggest making allowance for approximately 1.5 mm. thickness of porcelain. Sokled (197) suggests it is best to leave this part of the preparation until last, as it is very easy to remove too much tooth structure, resulting in a crown with poor support which is liable to fracture regardless of its thickness. Adequate support for the porcelain must be considered at all times, and for this reason, when reducing the occlusal surfaces of a premolar or molar, the general shape of the cusps must be preserved, as these shapes are best designed to resist lateral stresses produced during occlusal excursions. Conod (234) discussed this principle at some length.

In the case of an anterior tooth, once again the general shape should be preserved. The shape of the incisal area depends upon the patient's occlusion, and the principle involved is to prepare the incisal area so that it will be at right angles to the general direction of thrusts from the opposing teeth. Sayre (138) gives the following examples for upper anterior teeth :



1. For Normal To Deep Overbite



2. For Edge-to-Edge Bite

3. For Crossbite

In the design he advocates for edge-to-edge bite, care would have to be taken to round the two "ridges" on the incisal, otherwise they would act as wedges and perhaps split the crown. As a general rule there should be no sharp edges or angles on any part of a tooth prepared to receive a porcelain jacket crown, as these are likely to induce a concentration of stresses in the overlying porcelain, possibly leading to fracture. This principle has been recognised for quite a long time. The only exception is the shoulder where sharp angles may exist at the junctions of axial wall and gingival floor, and root surface and gingival floor. In this area the porcelain will tend to round off slightly during the glaze bake in any case.

Sayre (138) states that the amount and location of tooth structure removed should be determined with the idea of supporting the porcelain, leaving as little unsupported or overhanging porcelain as is possible, rather than depending on the bulk or mass of material for strength or resistance to stress. In short, the resistance form is the shape given to the tooth preparation that will enable the restoration to best withstand the stresses of mastication.

He also states that retention form is so closely allied to resistance form that there is little difference so far as the preparation is concerned. Convergence towards the incisal or occlusal surface should not be more than one degree from the right angle shoulder at the gingival surface, merely enough to allow for removal of the impression without distortion, he says. Lavis (270) suggests that the angle of convergence of the axial walls should not exceed five degrees. He also emphasises the importance of maintaining the shape of the cingulum when reducing the lingual surface of anterior teeth, as this permits a degree of parallelism between the labial and lingual surfaces of the preparation, improving both retention and support of the restoration.

Though much lip service is paid to these principles in the literature, one continually sees photographs of practical cases where they have not been observed, and the preparations have far too much taper (201, 216). As Sayre (138) observed, the more we depart from the principles of proper tooth preparation, the more do we court disaster.

Le Gro (45), Brecker (166, 256), and Cohen (153) have all written books covering the preparation of every tooth in the mouth for a porcelain jacket crown, and it is not intended to reproduce this information in this critical review. I find myself substantially in agreement with these men except that where they advocate no shoulder, I would suggest that a narrow finishing line be cut, as this removes the necessity for a knife edge of porcelain and also simplifies the technical procedures involved in constructing the crown. Since these books were written, methods of removing tooth structure have changed, but the ultimate shape of the preparation has changed little over the years.

Atypical Preparations (Vital Teeth)

The ideal preparation for vital teeth has just been described in general terms, but it is mainly applied to anterior teeth which are relatively sound, but have disfigured enamel due to hypoplasia, hypocalcification, fluorosis etc., or to teeth which are involved in a rehabilitation designed to produce an increase in the vertical dimension of occlusion.

More commonly, a tooth in need of a porcelain jacket crown has been mutilated by caries, accidental damage, or congenital malformation. Anterior teeth with small to medium sized proximal cavities are better treated with intracoronal restorations. Probably the most common indication for a porcelain jacket crown is the upper anterior tooth with one or both incisal angles attacked by caries in such a way that restoration by other means would require some sacrifice in aesthetics, a sacrifice to which the patient objects.

In the last example mentioned, extensive carious involvement of incisal angles tends to result in a finished preparation which has too much taper or convergence of its mesial and distal axial surfaces. As pointed out before, this excessive taper is undesirable, but if the labial and lingual walls can be prepared nearly parallel, and the mesial and distal shoulders can be widened slightly so as to make the mesial and distal axial surfaces more nearly parallel, and the preparation has adequate length, then it may still satisfy the requirements without the need for a gold casting.

However, caution must be exercised regarding deep preparation of the mesial and distal walls, not only because of possible danger to the pulp, but because a preparation which is too narrow mesiodistally will result in a porcelain jacket crown of uneven thickness. Also, in the case of an anterior tooth, pressure exerted during occlusion at the mesial or distal of the finished crown will generate a torque which will be poorly resisted by the narrow preparation. That is, the crown will have a tendency to rotate on the preparation, and the result may be failure of the restoration due to vertical splitting.

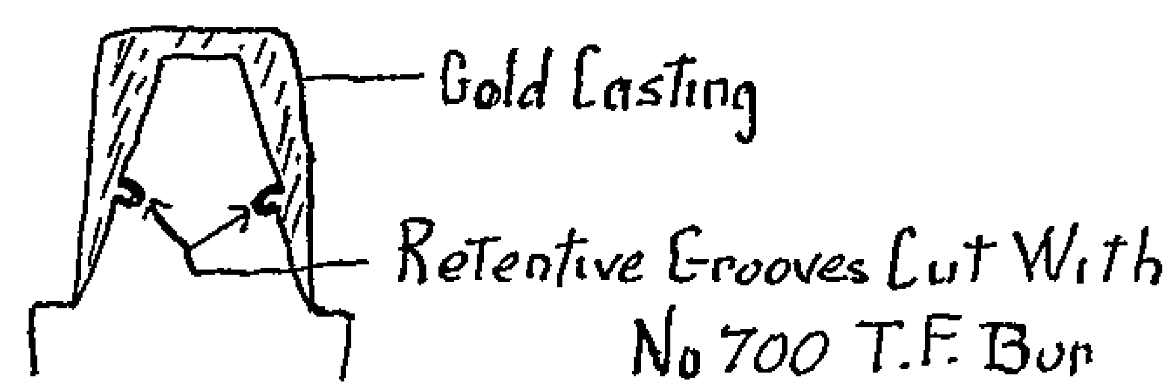
It is therefore necessary to employ discretion in such cases, and if in doubt it is better policy to restore the prepared tooth to a more nearly ideal shape by the placement of gold castings of suitable shape, designed to strengthen the remaining tooth structure. These castings usually take the form of thin thimbles or veneers as advocated by Hagen (160).

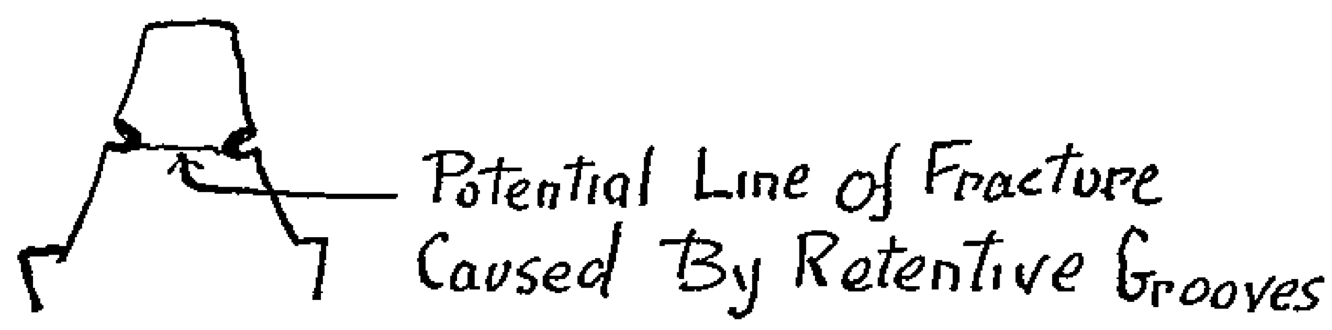
Brecker (261) gives the following indications for the cast gold copings:

1. Too short a preparation
2. Too narrow a preparation
3. When cement cannot be retained in excavated deep cavities.
4. Fractured and badly broken down teeth.
5. A cone shaped preparation
6. A hypoplastic or peg shaped tooth.

Richard and Brodtmann (229) say that cast copings are used when the remainder of a tooth is destroyed by caries or trauma, and a minimal surface remains for the construction of a jacket crown. The inclination of the end of the remaining tooth structure determines, they say, the direction of insertion of the coping. These authors prefer to have a path of insertion approximately at right angles to the long axis of the tooth rather than the more conventional thimble type of coping, whose path of insertion is approximately parallel to the long axis of the tooth. They depend upon parallel grooves for retention of the casting.

This path of insertion has the advantage of locking the casting in place when the porcelain jacket crown is cemented over it. However, such a casting does not tend to protect the remaining tooth structure, and the parallel grooves may very well weaken the tooth, leading to a subsequent fracture.





Brecker (168) suggests that in the case of the peg shaped lateral incisor, very little preparation is usually required. In order to prevent the completed crown from having a tendency to rotate on the somewhat conical preparation, Brecker suggests the preparation of a flat surface on the labial and lingual sides of the tooth. Shallow axial grooves could also be used. He says that though the use of a gold coping is sometimes an adjunct in overcoming a short tapered preparation, this procedure makes it difficult to bake a crown of ideal colour (on such a small and conspicuous tooth), and he therefore suggests that it only be resorted to in extreme cases.

Pincus (112) says that quite a bit of strength may be had in short bite cases with short teeth by extending the shoulderfurther under the tissue. He states that retraction for this purpose can be obtained by the use of a temporary crown. The above measures, he claims, will often double the retentive value of the crown. This is one of the few cases in which radical retraction prior to the preparation seems justified.

Millard and Stein (121) discuss the problems involved in restoring severely abraded anterior teeth with porcelain jacket crowns when planning a full mouth rehabilitation to restore a patient's lost vertical dimension of occlusion. In such cases the teeth often do not present enough structure to make a satisfactory preparation for a porcelain jacket crown. They state that some operators root fill such teeth and construct gold cores or cast bases with posts in the root canals. Millard and Stein criticise this as an unnecessary sacrifice, except where the pulp is exposed or diseased.

They suggest the following procedure:

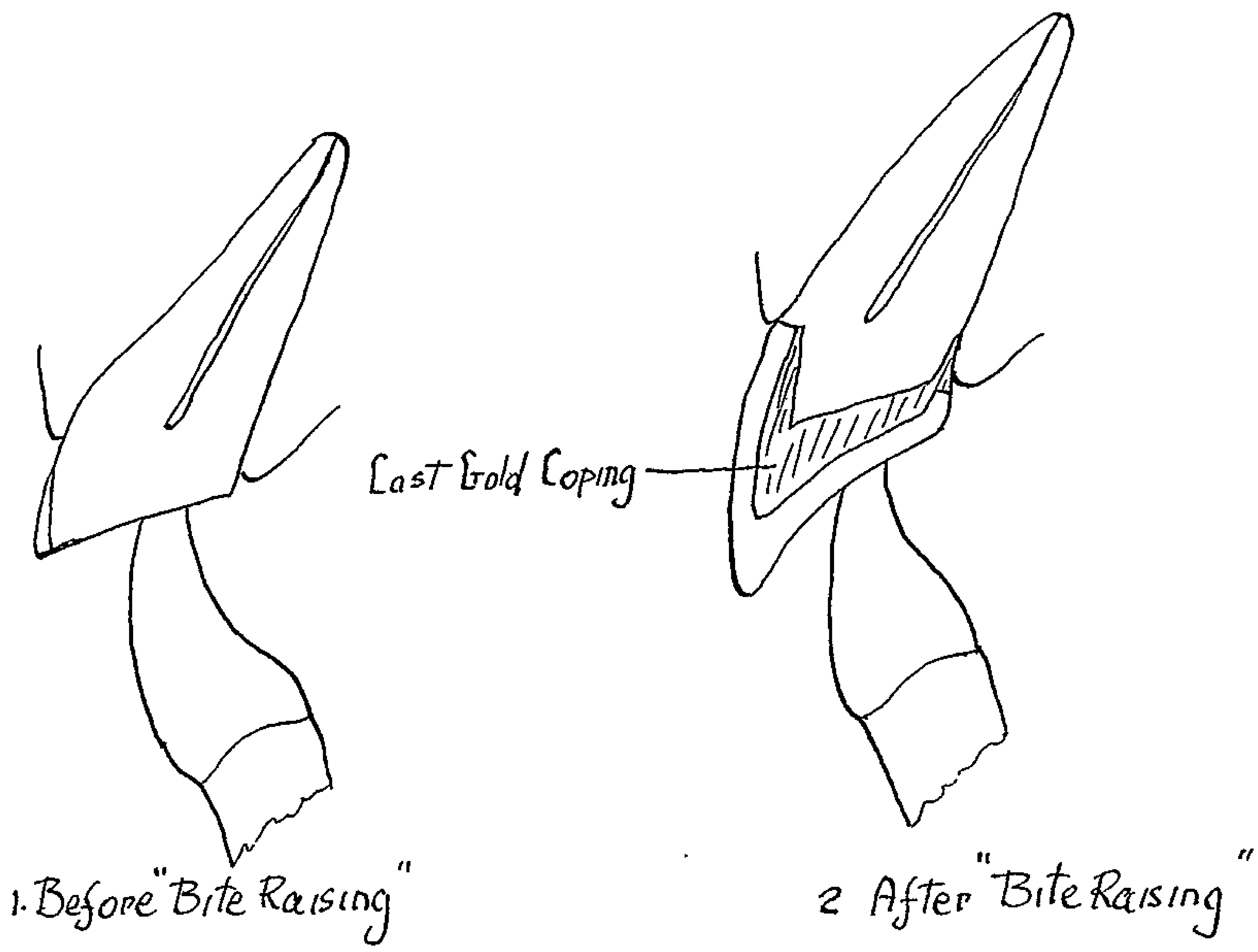
1. Remove the undercuts in the remaining portions of the crowns by slightly trimming with stones and discs.
2. Construct temporary base metal crowns which are then partially filled with baseplate gutta percha and forced over the teeth so that the gingival tissue will be forced away. These crowns are worn for several days until the gum has receded 1.5 to 2.0 mm. During this period they may have to be repacked two or three times.

3. After the gum has been forced away the teeth are tapered slightly towards the incisal.
4. The preparation may be made with a labial shoulder only, or left shoulderless.

Gold copings are then constructed, with an open labial face if desired, but leaving a labial cervical collar of gold for strength. Millard and Stein state that three quarter crown types of preparations for copings are contraindicated in this work because the remaining usable tooth structure is neither long enough nor strong enough for retention. A shoulder is formed in the gold coping at the normal gum line, as the gold will be sufficiently thick in this region. If a labial shoulder has been employed in the tooth preparation, the casting is terminated at this level so that no labial gold will be visible, even if subsequent gingival recession exposes this area to view.

The authors state that the coping performs three functions. By means of the apron it affords strong retention, it creates a shoulder around the root without the sacrifice of tooth structure, and it permits the necessary elongation for the porcelain jacket crown preparation.

It would appear to be good practice in the case of upper central incisors and upper and lower canines to increase retention and support of the gold coping on the necessarily short preparation by the use of parallel pins sunk into the dentine. This procedure would obviously not be suitable for teeth with very small diameter roots, for instance lower incisors and upper lateral incisors.



Above is shown a tracing taken from one of Millard and Stein's illustrations. As can be seen, there appears to be adequate support and retention for the porcelain jacket, but not for the gold coping beneath it. It may now well be simpler and equally satisfactory in such cases to employ the more modern porcelain fused to metal crown.

When a large cervical restoration is present in a tooth which is to receive a porcelain jacket, Ewing (174) suggests that the restoration should be removed if defective and replaced with the proper shade of cement. He advises leaving the preparation shoulderless in this region with the crown extended to cover the cement. Keller (187) agrees with Ewing that if rubber dam cannot be placed, the cavity should be filled with cement and the preparation left shoulderless in this region, but if rubber dam can be placed, then he prefers to cut a shoulder. In a similar situation Dunworth (190) suggests restoring the cervical area with gold foil and preparing a normal shoulder in the foil just as if it was sound tooth structure. This latter procedure is time consuming and does not produce such a good aesthetic result. Its use requires placement of rubber dam, good access, and a dry field, and if this can be accomplished there seems no reason why the deficiency cannot be filled in with cement and the porcelain extended sufficiently to cover this region.

Preparation of Pulpless Teeth

Ward (226) states that this form of treatment is only desirable on a root which is biologically sound and where root canal therapy has been successful. He does not explain exactly what is meant by the term "biologically sound" and how this desirable state can be assessed. In practice the success of a completed root canal therapy is assessed firstly from an X-ray picture which should show if the root canal has been "filled" to the desired level, and secondly whether the tooth feels comfortable to the patient. A period of a few weeks should be allowed following completion of a root canal therapy before proceeding with the restoration of the crown, in case there is any flare up of infection. Even if there is only a vague feeling of discomfort reported by the patient, the preparation should be delayed until this subsides.

Frequently one is confronted with a tooth which the X-ray shows to be incompletely root filled, but apparently healthy. The tooth may have given satisfactory service for many years but it is a wise precaution to redo the root filling and wait a couple of weeks to ensure success. I well remember a recent case of a patient presenting with a large acute abscess on an upper central incisor which had been root filled a few millimetres short of the apex some thirty years previously. The tooth had given the patient no previous symptoms of trouble. It can readily be appreciated that should any flare up occur following the cementation of some type of post into the root canal, it may be extremely difficult to treat other than by extraction if the post cannot be removed. Hence it is always better to play safe in these cases.

It is preferable, Ward (226) says, to use a root filling material that may be removed by careful manipulation in such a way that the material will not be removed from the apical area of the root canal. This area must remain sealed throughout the whole operation. He says that one effective method of root canal filling is described by Nicholls (227) where sectional root filling is undertaken with a short silver point inserted at the apical region. The root canal may then be reamed for reception of a post, leaving the silver point intact and sealing off the post from any contact with the apical tissues.

There is one disadvantage with this technique in that should there be any flareup following insertion of the silver point, this point will be impossible to remove and one must resort to either apicectomy or extraction. There seems to be no valid reason for not using a correspondingly short gutta percha point which can be readily removed if necessary.

It was soon recognised that pulpless teeth prepared for porcelain jacket crowns were prone to fracture unless suitably reinforced. In 1921 Felcher (34) described a technique for building up a pulpless tooth by means of a casting with a pin extending down the root canal.

Writing in 1923 Bastian (35) entered a plea for preservation of the remaining crown structure. He stated "Some operators, in restoring pulpless teeth, deliberately cut away all the natural remaining crown and use the post and casting for the sole support of the jacket. This method should be condemned on account of the needless destruction of the tooth tissue".

It is my own view that in many cases caries, the enlargement of the pulp chamber required to gain proper access for successful root canal treatment, plus the tooth structure removed during the preparation leaves only a thin and brittle shell of dentine which makes a very poor support for the restoration. In such cases it is much safer policy to remove this remaining weakened tooth structure and replace it with either a hard gold casting, or, in the case of a premolar, with amalgam reinforced by stainless steel threaded wire pins, as advocated by Markley.

Oppice (62) writes that the finished preparation on pulpless tooth is the same as that for teeth containing vital pulps, although the technical procedures involved are different. In all cases the post must have adequate length, at least equal to the length of the finished crown, and steps must be taken in the preparation by the provision of properly placed pin holes, grooves, or planes in order to prevent any tendency towards rotation of the finished core. Oppice describes both full and partial cast cores.

1. <u>The Full Core.</u>

The surface of the root is ground so as to be on a level with the soft tissues surrounding it, i.e. with the free margin of the gingiva. A cast precious metal core is constructed to resemble the dentinal portion of the original crown, except at the gingival aspect where a definite shoulder of tooth structure is left protruding beyond the core.

After this metal core has been cemented into place, the shoulder is carried into the area of the gingival crevice with an end-cutting bur. Pines (162) says that when the shoulder is cut below the gum margin, it becomes necessary to place a temporary crown form on the root in such a manner that the gingival tissue will be prevented from growing over the root. This, he says, causes irritation and if the crown should become loose between visits, the gum will grow over the root and it is quite difficult to get it back without undue pressure or inflammation. Hence it is better to extend the shoulder to the desired level after the core has been cemented. Ward (226) agrees with this procedure.

In the case of weakened roots Le Gro (47) advocates the use of a gold collar, the surface of the root being prepared with four beveled faces as advocated by H.E.S.Chayes. On three of the four sides a plain bevel is left, but at the labial a normal shoulder is cut. Brecker (169), writing in 1951, suggested the use of a core casting with a gold collar for fragile roots but ten years later (261) he states that he dislikes the use of gold collars on core castings and that it is wishful thinking to assume that a small collar of gold will prevent the splitting of the root.

2. <u>The Partial Core.</u>

Oppice (62) says that many pulpless teeth have enough coronal dentine remaining to permit the use of a partial core.

Ewing (174) suggests that it is desirable to retain as much natural tooth structure as is available. When most of the natural crown is present a dowel or post of suitable size may be cemented into the root canal before the preparation is commenced, he says. Occasionally carious areas will exist under the gingival margins and in these cases Ewing suggests extending the gold casting into these areas, the final preparation and polishing being done after cementation of the core.

Ward (226) states that where a root is particularly short, for instance following a too-radical apicectomy, it is advisable to retain as much tooth structure in the crown as possible, thereby improving the support and retention for the metal post.

Brecker (261) says that if some sound tooth structure remains at the cervical it should be utilised, as its presence promotes a better colour in the porcelain in this area. This does not seem to be a valid reason, because in the case of a pulpless tooth we have far more latitude in the matter of the thickness of porcelain. Thus it is a relatively simple matter to provide for an adequate thickness of porcelain in the cervical region so that a base layer of opaque or semi-opaque porcelain can be used to mask the underlying gold core.

3. <u>Cores for Roots with Subgingival Fractures.</u>

Pincus (162) suggests that when the root has caries or is fractured a great distance under the gum margin, the gold core is so constructed that the gold will fit flush with the margin of the break, and the shoulder at this area of the preparation will be in gold.

Nuttall (217) discusses this problem in a little more detail. He says that where an upper incisor has sustained a fracture involving the pulp and extending subgingivally on the lingual surface, the root canal is cleaned out, and a temporary post is placed carrying a temporary crown with an extension subgingivally replacing the fractured tooth structure. If the lingual subgingival tooth fragment is available, it is duplicated in cold cure resin in a split stone mould and attached to the resin temporary crown. This maintains the gingival and periodontal tissues in their proper position and prevents their hypertrophy. After root treatment and when the soft tissues have healed, a cast core is constructed with an extension replacing the missing subgingival tooth structure.

<u>Construction of the Core.</u>

For upper and lower anterior pulpless teeth, the cores are usually constructed from a hard cast gold, although the post may be of wrought gold if desired. Cores for premolars and molars, because they have greater bulk, may be constructed from amalgam reinforced by multiple stainless steel threaded wire pins cemented into holes drilled in the root structure, as advocated by Markley.

Bailey and Speed (183), writing in 1954, reported on the use of a metal post in the root canal over which a core was built up in cold cure acrylic resin. They claimed the following advantages:

(1) Laboratory time and expense in waxing and casting the gold core is eliminated.

(2) The preparation has a shade comparable to a crown preparation on a vital tooth.

(3) A preparation can be made in one visit and takes only slightly more time than a vital tooth preparation.

(4) The preparation is more economical because of time and materials saved.

At the time of writing, these authors had only used this technique for two patients, so it had not been thoroughly tested. An examination of the physical properties of acrylic resin shows there is a distinct possibility that, given time, the resin will exhibit sufficient flow for the crown to become detached due to fracture of the cement, or for the porcelain to fracture due to lack of support. In spite of the advantages claimed by the authors, it cannot be classed as satisfactory from a long term point of view.

To overcome the colour problem when gold cores are used, Ewing (174) suggests a labial box out in the gold core and filled with acrylic resin or silicate cement. There does not seem to be anything against this practice for upper anterior teeth as the core should still have adequate strength in the important incisal and lingual areas. However it is doubtful if there is any real aesthetic advantage over an all-gold core if sufficient thickness of porcelain is obtainable to permit the use of an opaque or semiopaque masking layer of porcelain next to the core.

Where it is desired to construct a cast gold core there are several methods of fabrication. Some authors condemn the use of a cast gold post on the grounds that it is not nearly as strong as a wrought gold post. Ward (226) says the prefabricated wrought gold post is much stronger in itself, but it is really impossible to obtain any form of accurate fit, and most gold posts of this type are actually just wedged in the root canal surrounded by cement. However he does say it is now possible to obtain special reamers for enlarging the root canal to a given size which will fit a known size of wrought gold post. The core is then cast onto the post giving a satisfactory result both for retention and strength.

Le Gro (47) suggests the use of a direct pattern with an inner core of 20 gauge roughened gold clasp wire extending down the root canal, this wire being left in place during the casting process. Le Gro believed that the resulting core was stronger than one entirely cast. This is true when compared to a soft cast gold, but with the more modern hard dental casting golds, (such as Class C inlay, or denture casting golds), especially if they are heat treated after casting, there is probably little to choose between the two methods.

Brecker (169) lists several methods for constructing a gold core for an anterior tooth:

(1) It can be constructed indirectly on a die, tried in the mouth for fit, and replaced in the die so that the porcelain jacket crown can be completed with the same die and models. This method has the disadvantage that the shoulder must be extended to its final level before the core is constructed. It also has another more serious disadvantage which is described later.

(2) It can be constructed indirectly before the shoulder is extended to its final level. The core is cemented, the shoulder extended to its final level, and a new set of impressions and centric registration taken so that new dies and models can be fabricated for construction of the porcelain jacket crown. This is a satisfactory but very laborious method, requiring as it does two sets of impressions, centric registrations, dies, and models.

(3) Brecker (169) suggests Gottlieb's technique (73) which is a direct one and appears to be very similar to that suggested by Le Gro (47) in 1925. The root canal is lubricated and a serrated platinum-iridium post is selected, 14 gauge for an upper central, 16 gauge for an upper lateral incisor. At least two or three millimetres must extend beyond the post hole. The other end is tapered and the post must not fit the canal snugly, otherwise there will be no room for wax. Kerr's medium fusing wax is softened into a cone and forced up the canal. The metal post is warmed and pushed up into the wax. This is allowed to cool, removed, and replaced. The core is then waxed up over the protruding post and checked throughout the range of occlusal movements. A sprue is attached and the pattern cast, leaving the platinum-iridium wire embedded in the casting.

(4) It can be waxed directly on the tooth around a long tapered copper post which also acts as a handle and sprue former. The copper post is heated and withdrawn from the mould before the casting is made. The only disadvantage with this method, which is otherwise quick, simple, and accurate, is that the occlusal or incisal clearance cannot be checked because the copper post protrudes. However this

is of little consequence, as the finished casting can be adjusted by inspection in the mouth before it is cemented. This is the method I prefer, but the two previous methods are equally capable of yielding satisfactory results. The first method described is liable to error if the core does not take up exactly the same position in the tooth as it did in the die. Should this happen, the porcelain jacket crown will not fit, and for this reason the first method of core construction described cannot be recommended.

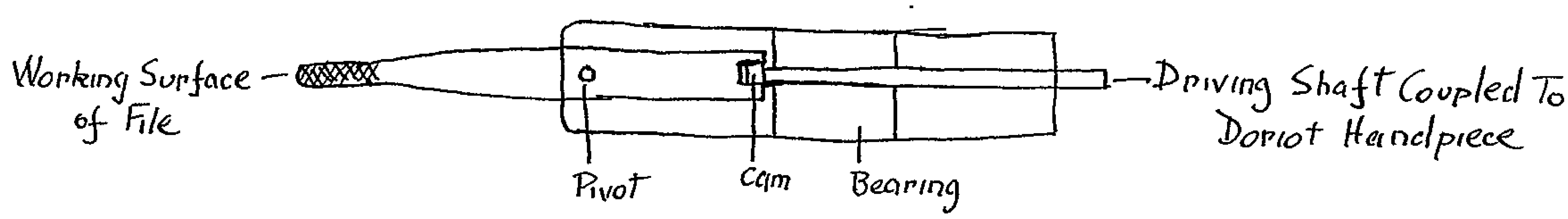
Ward (226) suggests that where a metal core has been used, the colour may be masked by mixing a small quantity of titanium oxide and the cement powder with water. This mixture is painted onto the metal core and carefully dried. Ward claims that the resulting white covering is sufficient to ensure the correct shade of the crown. He does not state what effect this coating has on the retention of the cemented crown. If the powder forms a film thick enough to mask the metal core it is quite possible that it would decrease the retention somewhat, though this has yet to be demonstrated. My own view is that it is preferable to carry out the preparation so that there will be sufficient thickness of porcelain to permit the incorporation of a base layer of opaque or semiopaque porcelain which will adequately mask the underlying metal.

Instrumentation.

In 1904 E.B.Spalding (11) described and illustrated a technique for preparing a vital tooth for a porcelain jacket crown. He used a thin 7/8" diameter carborundum disc running at what he described as "high speed" to reduce the mesial and distal surfaces of the tooth. The disc was water cooled with a syringe by an assistant in order to dissipate the frictional heat produced. The labial and lingual surfaces were prepared with burs and stones, and the finished preparation resembled the conventional shoulder type of preparation in use today.

Avery (18) in 1915 and most of his contemporaries, appreciated the importance of not overheating the tooth during preparation. Some operators advocated the use of an air blast instead of water as a coolant. However it has been shown that a prolonged blast of air desiccates the dentine, is painful to the patient, and may produce pulpal injury in some cases. Also it is not such an effective coolant.

Bastian (35) in 1923 designed a set of hand shoulder files bearing his name, and these are still in use for removing bur cuts and other irregularities at the shoulder of the preparation. Smith (89) in 1931 attempted to adapt a similar type of file for use in a handpiece. By means of a cam the file was given a reciprocating motion. This instrument was apparently not produced in quantity, and I have never seen one so cannot judge whether it is effective, but it would be likely to produce a good deal of vibration. It was made up as follows :



Tenner (113) in 1937 said he had discarded carborundum stones in favour of the diamond variety. He claimed that with these fast cutting stones it was not necessary to cut the enamel into squares to be subsequently split off with a chisel. He removed the gingival collar of enamel with Cases enamel cleavers, and smoothed the preparation with paper discs. The shoulder was prepared under the gingival margin using tapered fissure, inverted cone, and end-cutting burs.

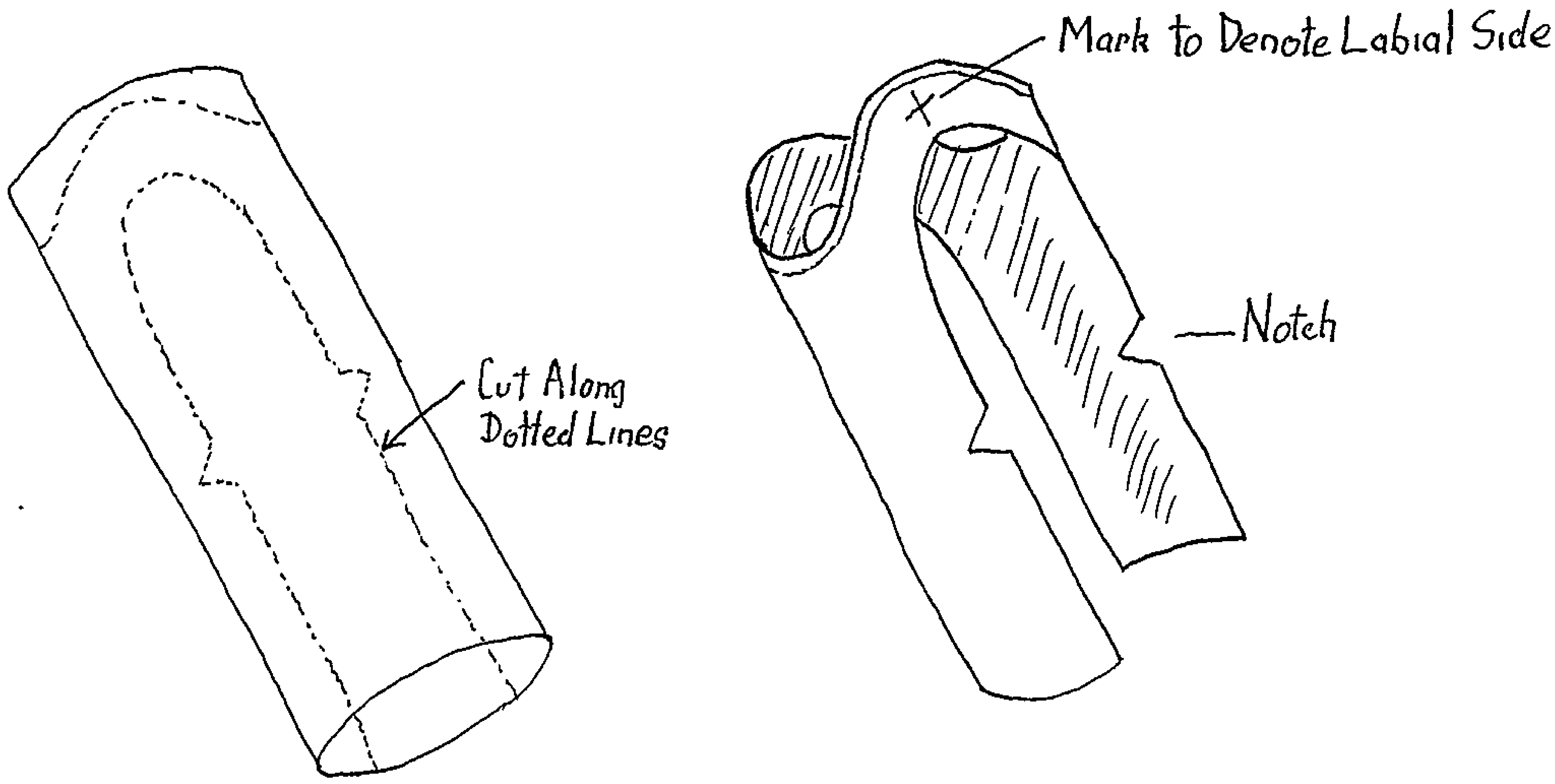
Wheeler (123) issued a warning in 1938 regarding the extreme curvature of the epithelial attachment on the mesial and distal surfaces of anterior teeth. He said that it was easy to strip the epithelial attachment in this region while using a separating disc. This warning is not misplaced, as it requires considerable skill to cut this area to follow the gingival contour with a disc. The tendency is to cut from labial to lingual in a straight line with the disc, cutting deep into the area of the interproximal crest of the attachment. Should this happen it will be necessary to forcibly retract this tissue still further in order to finish the proximal shoulder and obtain a satisfactory impression. Such procedures are often the start of progressive gingival deterioration.

For this reason I for one celebrate the eclipse of the disc by the fissure-shaped small tungsten carbide or diamond instrument used in the ultra high speed (300,000 - 450,000 R.P.M.) air turbine handpiece. There is no danger involved should this instrument become jammed, owing to its relatively low inertia. Also, its lessened vibration makes it rather more comfortable for the patient, and it can be used to follow the outline of the gingival crest and the curvature of the axial wall of the tooth far more easily than can a disc.

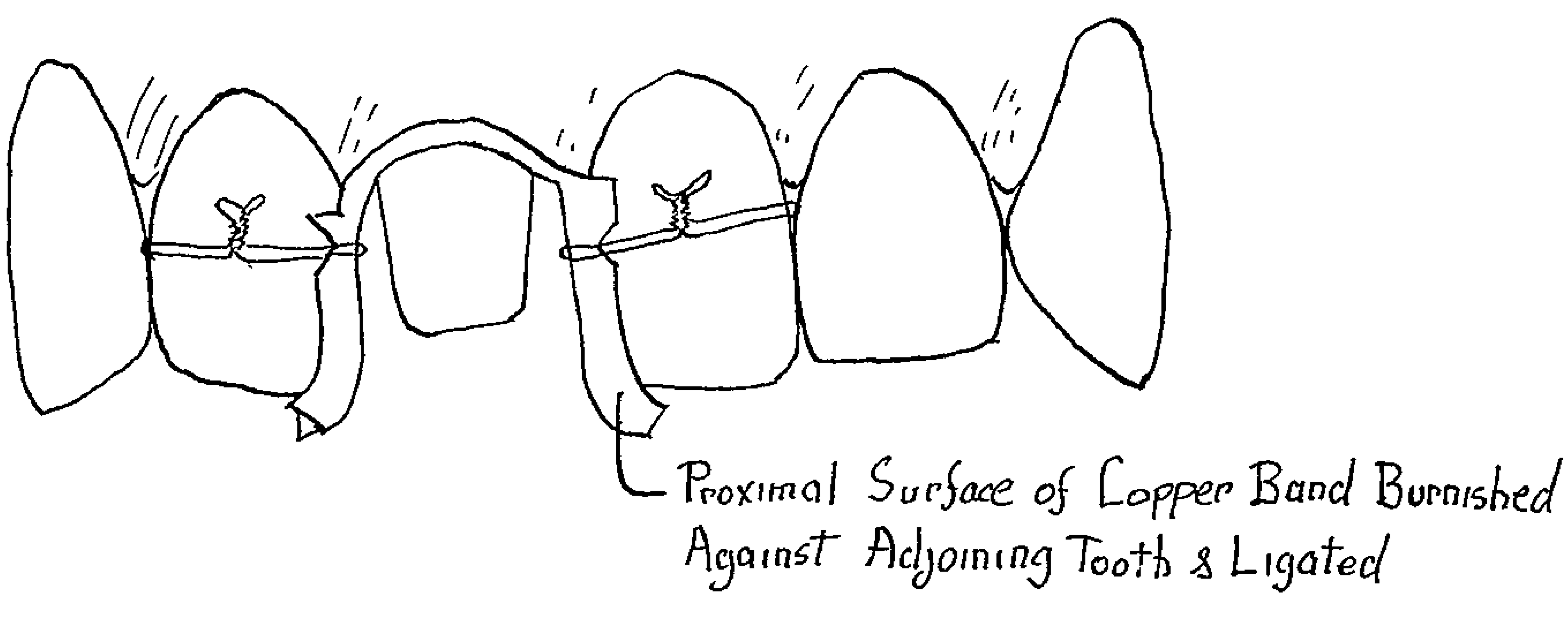
Hovestadt (42) in 1925 advocated the use of local anaesthesia when preparing a vital tooth, but Both (126) and other writers considered it safer to prepare a vital tooth without anaesthesia. Both claimed the use of stones in conjunction with a warm water spray would reduce pain to a low level and avoid trauma to the tooth. We now consider the use of a warm water spray is desirable whether anaesthesia is used or not. Certainly the use of a water spray (warm or cold) is absolutely necessary where high speed cutting is employed, otherwise the frictional heat generated will do considerable damage to the pulp.

I feel strongly that the question of whether to use local anaesthesia for preparation of a vital tooth is best left to the patient. It is good practice to commence the preparation without anaesthesia, informing the patient that should they desire local anaesthesia, they have only to make the request. This is, in my opinion, far better psychology than informing the patient flatly that the preparation will be carried out without anaesthesia. Such an inflexible attitude imparts to the patient the feeling that the preparation of the tooth is to be a painful ordeal, they instinctively become tense, and as a result the pain threshold is lowered. It is desirable to work without anaesthesia as there is immediate warning if the cutting instrument is developing too much frictional heat, but if careful intermittent cutting is used, there seems no reason why the preparation of a vital tooth cannot be safely carried out under local anaesthesia if the patient desires it.

Novales (128) in 1940 stated that as the shoulder of a porcelain jacket crown preparation is carried out beneath the free margin of the gingiva, it is not possible to use the rubber dam. He claimed that up until that time it was not possible for the operator to trim the shoulder without lacerating the marginal gingiva, which bleeds profusely, flooding the operative field. Novales evolved a copper matrix, trimmed to follow the shape of the gingival margin, and so adapted under it as to serve as a dam, moving away the free gingiva so that the burs and other instruments would not come in contact with it. An annealed copper band was festooned and adapted as follows :



The assembly is now shown in position :



When the above apparatus has been placed in position, Novales claims that it is possible to deepen the shoulder with end and side cutting burs, extending it under the free border of the gingiva in a dry and clean operative field. It is my view that this whole procedure is clumsy, time-consuming, unnecessary, and liable to injure the epithelial attachment. In short, there seems nothing to recommend it.

Hagen (160) apparently did not experience difficulty in applying rubber dam to a tooth to be prepared for a porcelain jacket crown. He applied the rubber dam with a cervical clamp before extending the shoulder fully. This, he claimed, allows the operator to have a clear field of vision and to finish the shoulder as in any fine cavity preparation.

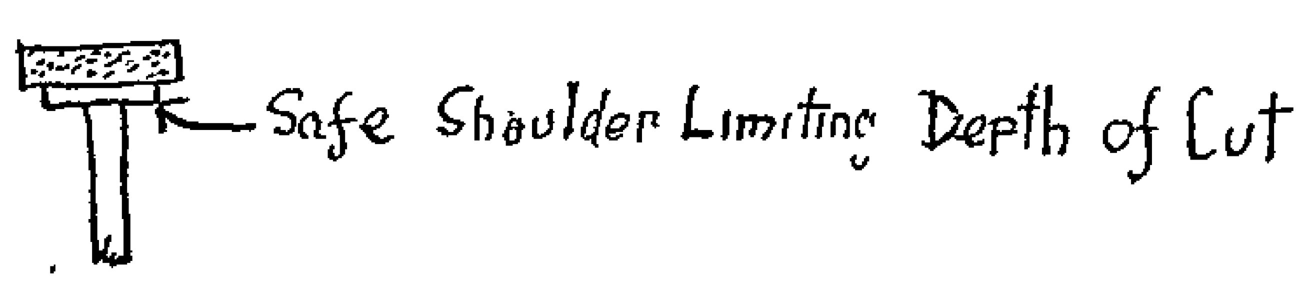
Heller (187) claimed in 1955 that rubber dam could be placed for a porcelain jacket crown preparation using a Ferrier 212 cervical clamp or similar, even when large carious or previously filled areas existed on the labial or lingual surfaces.

My own experience with rubber dam is that in the majority of cases it can be placed on a tooth intended to receive a porcelain jacket crown restoration with the aid of a suitable cervical clamp either before,during, or after completion of the preparation. I would question whether there is need to place the dam before or during the preparation, as sufficient dryness for final finishing of the details of the preparation can be attained by the judicious use of cotton rolls. However the final cementation of the restoration is another matter because absolute dryness is essential, and sometimes this can only be achieved by the proper placement of rubber dam. This is not to say that rubber dam is absolutely essential for proper cementation of every case, because if dryness can be maintained by simpler means, then there is no point in resorting to the use of rubber dam.

In 1945 Bury (148) suggested a novel method for preparing a vital tooth. He first reduced the incisal edge with a stone, then cut with a 700 tapering fissure bur at the dentinoenamel junction, splitting off the undermined enamel with a chisel as cutting progressed. Bury claimed that his technique ensures that a uniform and sufficient quantity of tooth structure is removed, and that the generation of heat in cutting is minimised. He said that the only precaution necessary is to keep the bur pressing against the enamel constantly and not to attempt to sink the bur deeper than 2 mm. before splitting off the enamel. It would seem that this method might remove too much tooth structure particularly on a tooth which is thin labiolingually. It is also slow and tedious.

As late as 1948 Hagen (160) still advocated the then superseded method of dividing the labial and lingual surfaces into squares and removing these with a 48 S chisel and mallet. While it may be argued that a fairly even cutting depth can be produced by this method, it is obviously also slow and tedious, and is no longer in use to any degree. However he did advocate an excellent idea in establishing the shoulder (for an upper anterior tooth) with a smooth (i.e. not crosscut) fissure bur of the latch type held in the straight handpiece. Hagen said this gives a grip on the bur almost like an engraving tool, and with light even strokes the proper depth and outline of the shoulder can be secured quickly. I have tried this idea myself and find that it works very well, the short bur head giving much better control. He suggests that an end-cutting bur be run lightly around the whole shoulder and the finishing accomplished with a No.83 binangled chisel. For the final finish he recommends the use of wet pumice with a rubber cup. One would need to exercise care not to overheat the tooth with this instrument.

Gruenwald (185) in 1955 advocated the use of diamond instruments with safe shoulders for preparing the labial and lingual surfaces of the tooth, but these seem to be rather clumsy instruments and of little assistance.



Diamond Stone Used on Labial & Lingual To Outline Shoulder

For Labial & Lingual Reduction

In 1955 Steen (193) described the preparation of a tooth for a porcelain jacket crown using the Cavitron ultrasonic dental instrument. This instrument vibrates about 30,000 times per second and those vibrations agitate aluminium oxide particles which flow in a water solution over the tip of the instrument, and which do the actual cutting of the tooth (molecular excavation) by extreme conformity with the cutting tip. The jacket crown preparation is done with four or five different tips and is accomplished in six definite and precise steps. Steen says the average conventional preparation requires approximately 30 minutes. With the ultrasonic instrument about the same length of time was required for the preparation, except that a smooth polished finish was imparted to the preparation making further polishing unnecessary.

Steen said that some slight sensation was noticed by a few patients when the dentinoenamel junction was crossed, however the most singular aspect of the ultrasonic jacket preparation in all cases handled to date is the great loss of noise, vibration, and pain without the use of local anaesthetic.

Since Steen published this paper the Cavitron instrument seems to have largely gone out of use for tooth preparation. Presumably, like the S.S. White air-abrasive unit, it has been superseded by the high and ultra-high speed rotary instruments, usually air turbine driven.

Handpieces, whether belt or turbine driven, with speeds of less than about 150,000 R.P.M. will require the use of discs to prepare the proximal surfaces of the teeth. If the fine tapered-fissure shaped tungsten carbide or diamond instruments are used at these speeds, they will cut too slowly to be effective. As previously explained, I consider discs to be too dangerous in use and to require too high a degree of skill in handling. For this reason the air driven ultra high speed turbine handpieces are to be preferred in my opinion.

Bastian (243) in 1959 said that with the advent of high speed handpieces, the preparation is carried out with small tungsten carbide or diamond instruments. He says that the lessened vibration and rapid cutting result in more comfort for the patient. Brecker (256) agrees with this, but also says that the greatest disadvantages are the inability to see what is being accomplished because of the water spray, and the fact that the tooth structure is reduced too rapidly.

I would agree that the water spray is a disadvantage at times, but disagree that the tooth structure is reduced too rapidly, as this last factor is under the control of the operator.

However I do agree with Brecker when he says that ideal preparations for any type of crown cannot be accomplished by using ultra high speed equipment alone. The final exactness and finishing of a shoulder slightly beneath the gingiva can best be created, he says, with instruments revolving at moderate speeds.

The stages in preparing vital teeth for porcelain jacket crowns with an air driven ultra, high speed turbine handpiece according to Brecker's ideas are shown by means of illustrations taken from his book (256).

These illustrations serve as an excellent guide, and the instrumentation can be varied slightly to suit the individual operator's preference. The preparation is smoothed by using finishing diamonds at moderate speeds in the air turbine handpiece, the water spray being used at all times with this handpiece.

This is followed by polishing with fine sandpaper discs (lubricated) in the slow speed handpiece. A sharp binangle or straight chisel, or a Bastian or Meissinger shoulder file will plane and smooth the surface of the shoulder better than any rotating instrument.

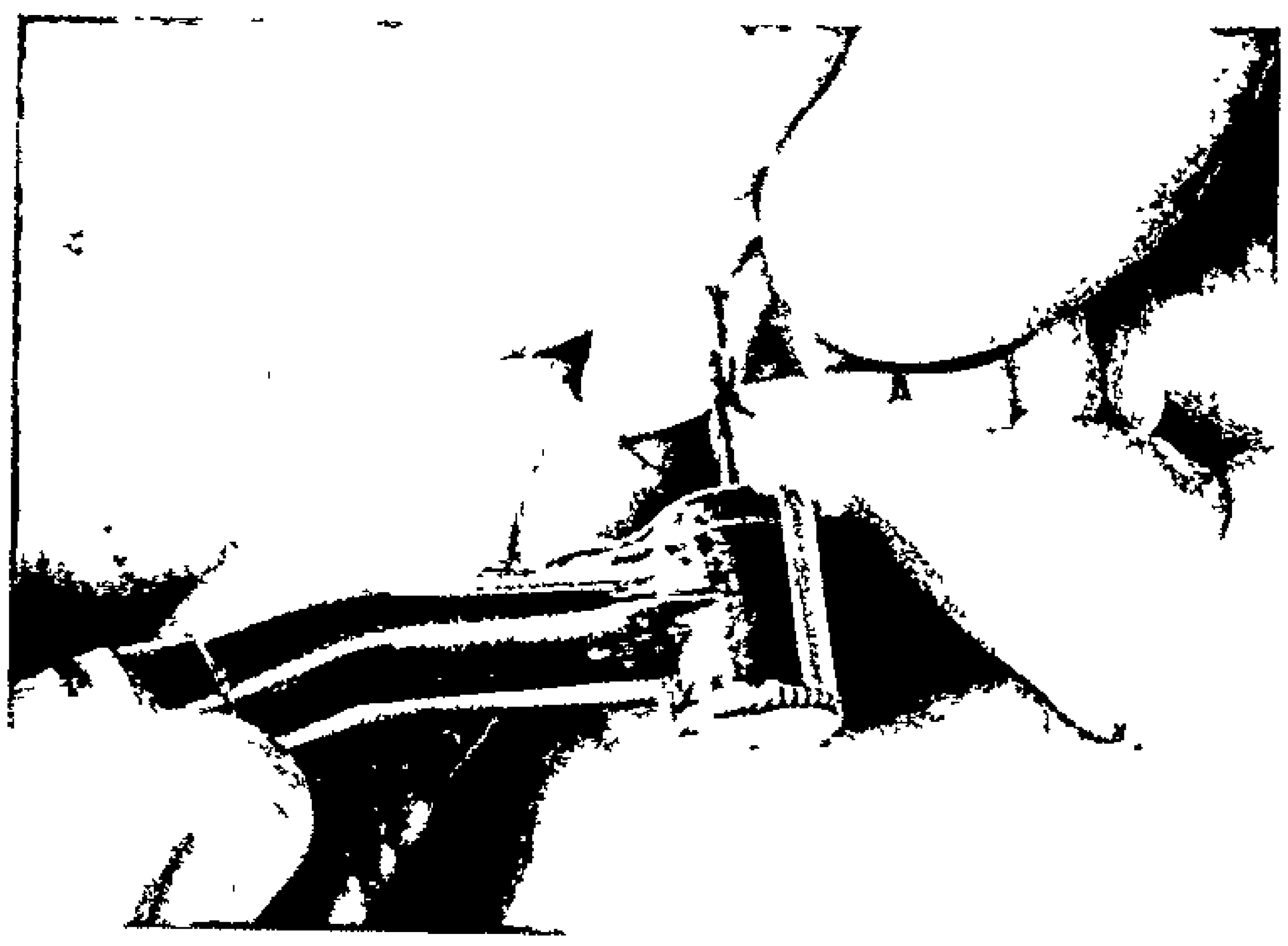


FIG. 240.

Step 1 (Fig. 240). Reduction of the Mesial and Distal Surfaces. The use of a steel matrix wrapped around the approximating teeth is sometimes recommended in order to "protect" the surfaces of the adjacent teeth. These matrices are available in assorted sizes. Although they are primarily designed for interproximal amalgam alloy restorations, they can serve as means to safeguard the approximating teeth when using burs in the ultra-high speed handpiece. In many instances, however, these burs rip and gouge into the steel matrix, thus the matrices can cause more harm than they are worth. The experienced operator can manage the interproximal break-through with thin tapering carbide burs. I still advise the use of safe-sided mounted diamond disks in the regular handpiece for the reduction of the mesial and distal surfaces. Remove sufficient tooth structure to permit the ultra-high speed carbide bur to engage these areas without fear of damaging the approximating teeth.

FIG. 241.

Step 2 (Fig. 241). Reduction of the Incisal Edge. Use a No. 57L plain or a 700L cross-cut fissure bur to remove the incisal edge. Place the bur as close to the edge of the tooth as possible and remove the tooth structure sufficiently to allow for thickness of porcelain or gold in this region. The incisal edge should be reduced before the labial or lingual surfaces because the average length of the bur or stone is much shorter than the average length of the anterior tooth (Fig. 247). Some operators prefer to use a small wheel stone to reduce the incisal surface.

Figs. 240-255 Reproduced From S.C. Brecker's Book, Reference (256)

Step 3 (Fig. 242). Reduction of the Labial and Proximal Surfaces. Place the same fissure bur as close to the reduced edge as possible and remove the labial enamel, creating a narrow shoulder that extends from the mesial surface around to the distal surface. Extend this shoulder in stages and in a cervical direction until all of the enamel is removed and the shoulder terminates as close to the gingiva as possible. The shorter the bur the greater the danger of creating a labial undercut. The operator is cautioned not to remove too much protective tooth substance. Long planers and oversize burs are usually impractical to use because they "whip" too much and snap off either at the junction with the shank or in the middle. Some operators prefer to use the tapered-cylinder diamond stone for the over-all reduction of the labial surface.

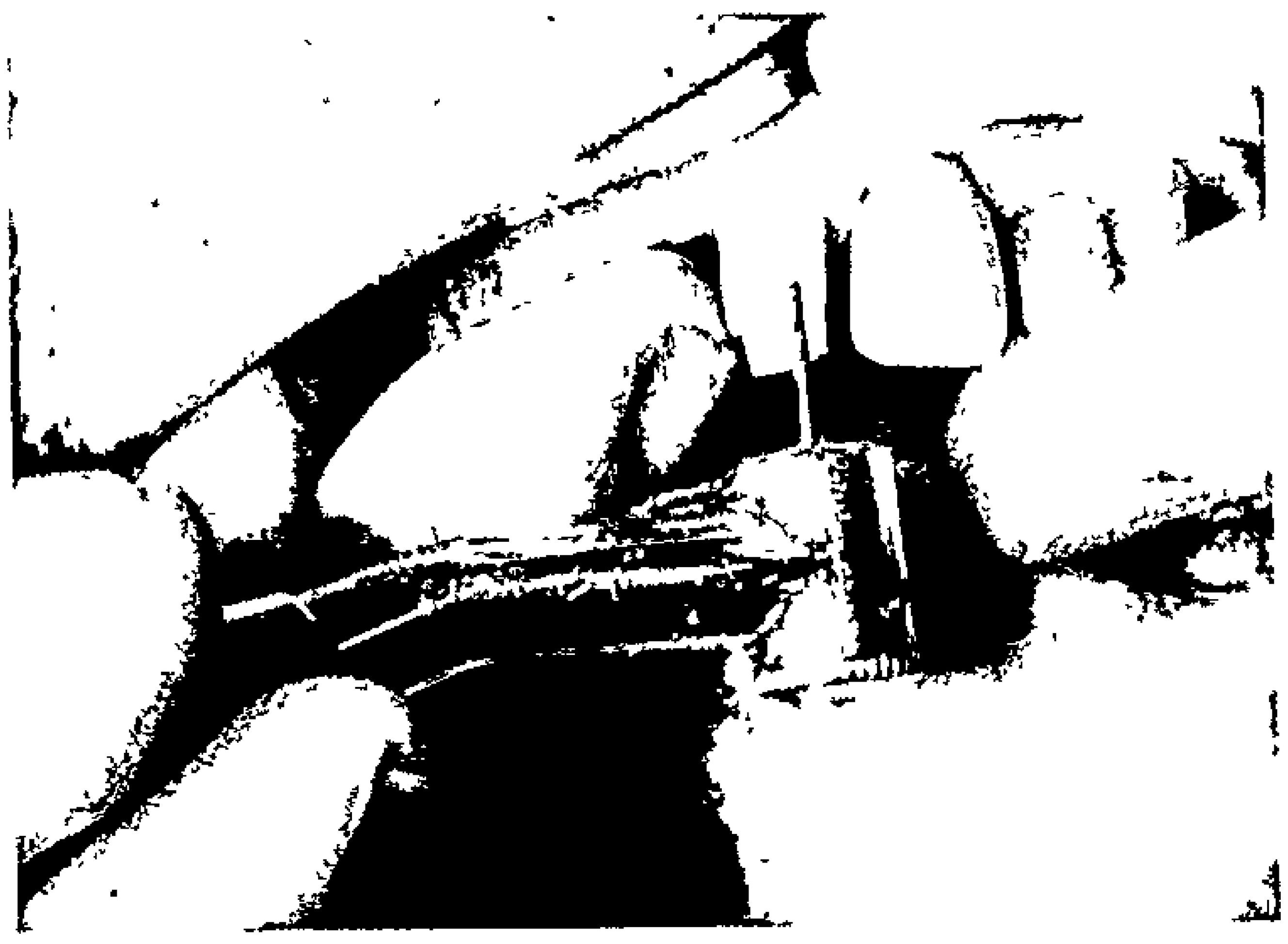


FIG. 242.

Step 4 (Fig. 243). Reduction of the Lingual Surface. Use the Densco No. ½J small diamond wheel stone to reduce the lingual area and the cingulum. It is convenient for accessibility to raise the dental chair and to tilt the patient's head back so the operator can get a direct view of the lingual surface. Be mindful that a copious flow of water from the coolant is directed onto the surface, practically obscuring vision. The reduction of the lingual surface is difficult, and only experienced operators can eventually succeed in preparing the area without serious damage. Burs often create nicks and gouges, and when one attempts to remove these irregularities, the pulp is jeopardized. Some operators use the mouth mirror with the surface smeared with a detergent so that the assistant can blow off the globules of water that drop onto the surface of the mirror. The operator can then see the lingual surface through the mirror while he is reducing the area. This procedure takes practice. There is danger that this small diamond wheel will touch the approximating teeth as it traverses from mesial to distal. This small wheel can be used with the rounded cutting edge or with the face against the tooth structure. It is frequently necessary for the assistant to pour water from the syringe onto the tooth in addition to the water from the coolant coming from the handpiece.

FIG. 243.

FIG. 244.

Step 5 (Fig. 244). Extending the Labial Shoulder and Rounding Sharp Angles. Use the same small diamond wheel stone to extend the labial shoulder closer to the gingiva, to remove the nicks created by the carbide bur and to round off sharp proximal line angles and sharp corners. Further reduction of the incisal edge is also accomplished with this small rounded-edge diamond wheel. Inasmuch as the water from the coolant does not cool the cutting face of the stone, it is imperative to stop frequently to prevent the "burning" of the enamel. It is a good policy, when stopping, to blow compressed air on the surface of the tooth to see if sufficient tooth structure is reduced. Remaining enamel, when dry, shows up in characteristic striated patterns, distinguishable from the dentin. There are operators who use only diamond stones to round off sharp angles. There are so many burs and stones available, of different designs and different numbers, that it rests with the operator with which stone or bur he obtains the best result.

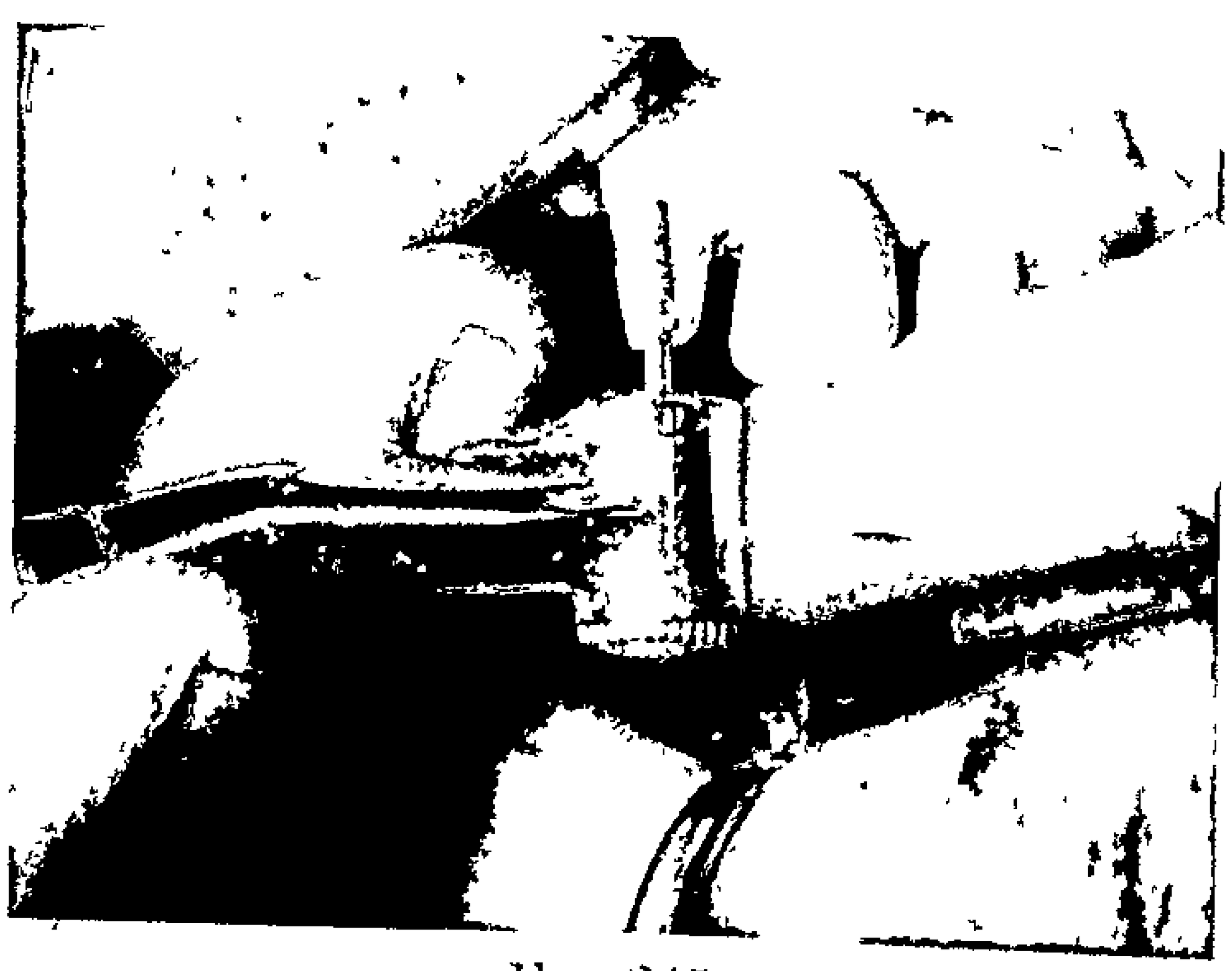


FIG. 245.

Step 6 (Fig. 245). Finishing and Smoothing the Preparation. Despite the claims of some, the shoulder can be extended accurately, and slightly beneath the gingival tissue, only with a cross-cut or end-cutting bur rotating at conventional speed. Control of such a bur will prevent tissue laceration. Smooth the accessible surfaces with the extra-fine grit diamond stones also rotating at moderate speed. These specially designed Densco finishing stones create a smooth surface on the preparation, removing all nicks caused by the carbide burs. Exercise care that the stone does not touch the approximating tooth.

Step 7 (Fig. 246). Final Smoothing of the Preparation. Smooth the entire preparation with sandpaper disks of fine grit, rotating at low speed. Be sure to lubricate the disk with petrolatum or cocoa butter to minimize overheating the tooth. A sharp bin-angle or straight chisel or a Bastian file will plane and smooth the surface of the shoulder better than any rotating instrument. Before taking the impression of the prepared tooth, examine all the surfaces carefully for undercuts. Ultra-high speed instruments tend to cause undercuts because they remove tooth structure so rapidly and because it is difficult to see what and how much is being removed.

FIG. 246.

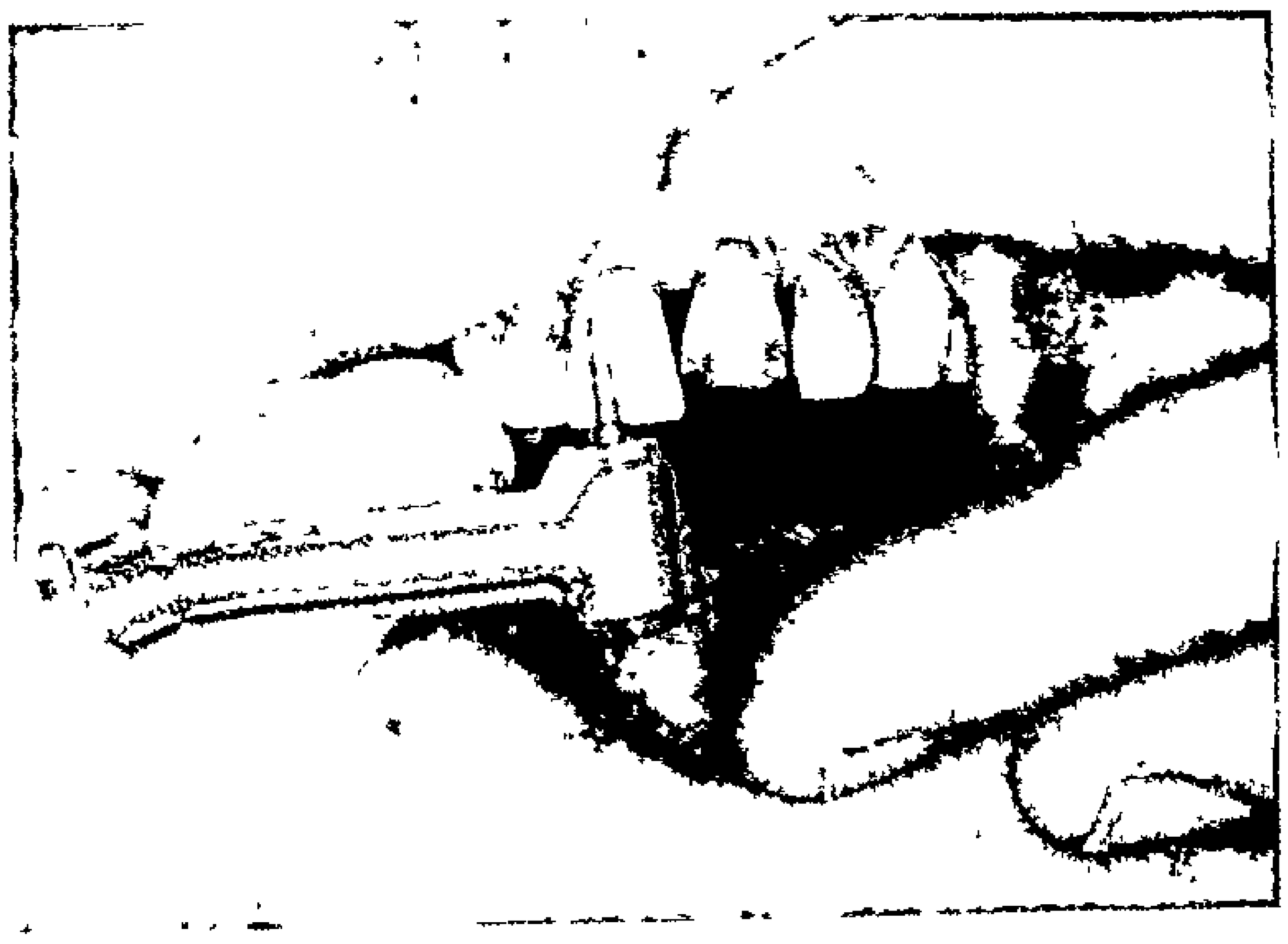


FIG. 247. The stone or bur manufactured for ultra-high speed handpieces is usually too short to cover the entire labial surface. Reduction of the incisal edge or occlusal surface before the labial and lingual areas is recommended to minimize undercuts when reducing the labial and lingual surfaces.

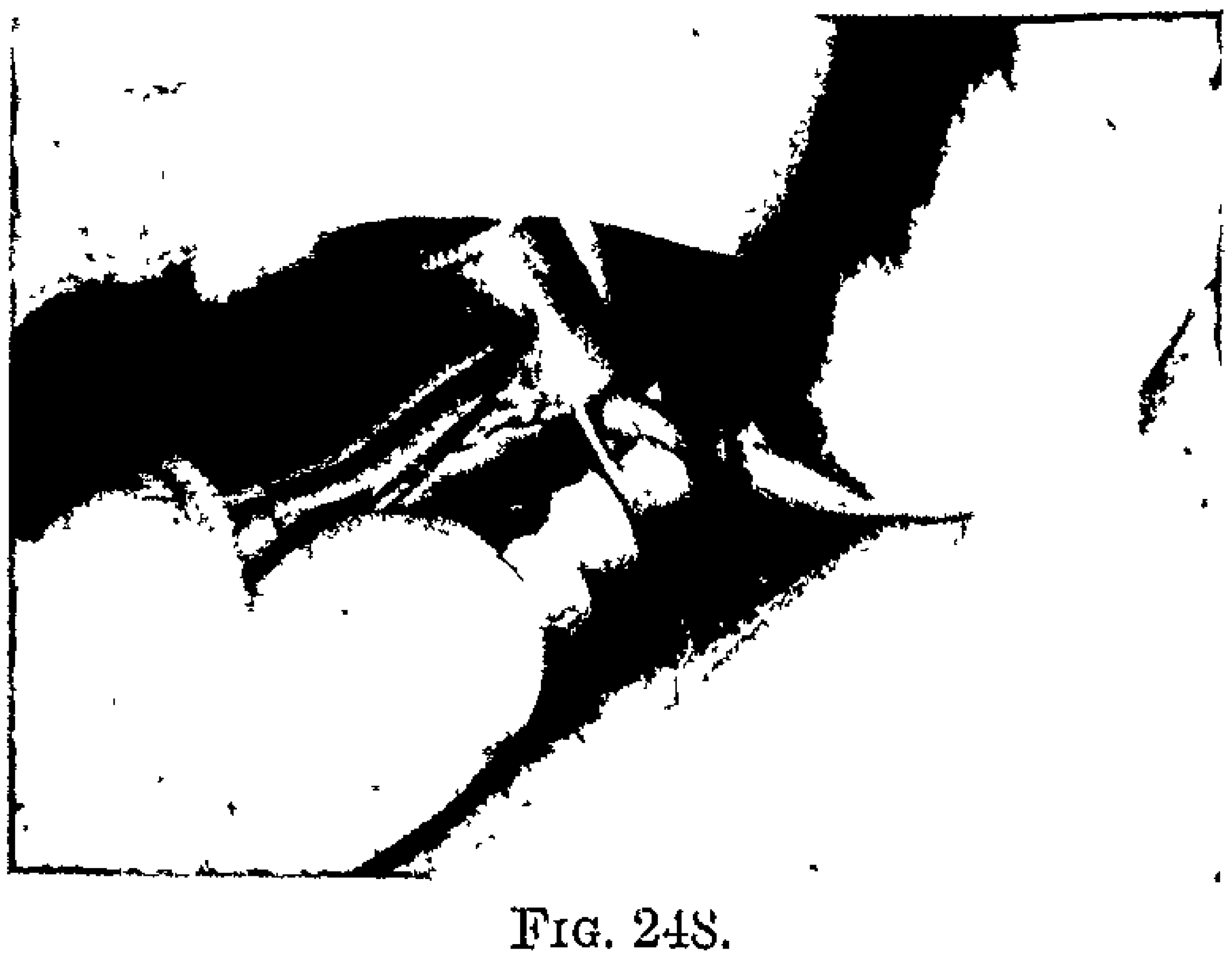


FIG. 248.

Step 1 (Fig. 248). Reduction of the Mesial and Distal Surfaces. It is advisable to reduce the mesial and distal surfaces of a molar with a safe-sided mounted diamond disk revolving at moderate speed in the conventional handpiece. This procedure will remove the tight contact areas without damaging the approximating surfaces of the adjacent teeth. The experienced operator, however, may use the long, thin, tapered carbide fissure bur in the ultra-high speed handpiece such as the No. 69L plain or the 699L cross-cut Densco burs. Care must be exercised that this bur does not touch the approximating teeth. Break through the marginal ridge, directing the bur *without pressure* against the proximal surface being reduced. Further reduction of the mesial and distal surfaces may be accomplished with a thin tapering diamond stone or a No. 701 fissure bur. For the preparation of mandibular molars it is advisable to seat the patient low and almost erect in the dental chair. Stop operating every so often and examine what is being accomplished.

FIG. 249.

Step 2 (Fig. 249). Reduction of the Occlusal Surface. The occlusal surface of a posterior tooth may be reduced with a No. 557 cross-cut fissure bur, a medium size inverted cone or with a small No. ½J Densco diamond wheel. The wheel stone, directed from the buccal or the lingual area and held at right angles to the long axis of the tooth, removes tooth structure occlusally. Do not permit the small diamond wheel stone to touch the approximating teeth. Some operators use the same small diamond wheel or cross-cut fissure bur for bulk reduction of accessible tooth structure throughout. It is sometimes convenient for an operator to use the rounded edge of the small wheel for gross reduction of the occlusal surface and then follow with a barrel-shaped or small cylinder diamond stone to eliminate irregularities.

Step 3 (Fig. 250). Reduction of the Buccal Surface. The bulbous buccal surface is reduced with a cross-cut fissure bur. Start from the reduced occlusal surface and remove some of the enamel about half-way down the buccal surface. Hold the bur parallel to the long axis of the tooth so as not to create an undercut. A slight shoulder is formed in the bucco-occlusal third as a guide. The handpiece is held in the side pen grasp with the ball of the middle finger resting upon the buccal surfaces of the mandibular premolars. Round off the junction of the buccal and proximal surfaces in the occlusal third of the tooth.

Fig. 250.

Step 4 (Fig. 251). Completing Reduction of the Buccal Surface. Extend the shoulder close to the gingival tissue with a long plain or cross-cut fissure bur, reducing the remaining enamel on the buccal surface. If the restoration is to be a veneer or a porcelain jacket crown then all of the enamel must be reduced from the buccal surface to allow for thickness of gold, porcelain or acrylic resin material. Do not exert pressure when using these long burs in the ultra-high speed handpiece.

Fig. 251.

Some operators prefer to use a tapered-cylinder diamond stone (Fig. 252) for the over-all reduction of the buccal and lingual surfaces. When using this type of stone, care must be exercised not to create an undercut and not to permit the stone to touch the gingival tissues or the adjacent teeth. This stone is often used to reduce the bulk of tooth structure from the occlusal surface as well. It is a good procedure to stop intermittently and examine the surface before continuing.

Fig. 252.

Fig. 253.

Step 5 (Fig. 253). Reduction of the Lingual Surface. The reduction of the lingual surface is accomplished with the same burs or stones and in the same sequence as recommended in the previous two steps. Retracting and safeguarding the tongue is of great importance. The handpiece is held in the side pen grasp with the ball of the middle finger retracting the lip and resting upon the buccal surfaces of the premolars. Be mindful that tooth structure is reduced rapidly and it is advantageous to stop intermittently to see that not too much protective tooth substance is removed. It is better to take off too little than too much.

Fig. 254.

Step 6 (Fig. 254). Finishing and Smoothing the Preparation. Remove any nicks and surface irregularities with one of the Densco diamond stones having extra-fine grit. To obtain best results, these finishing diamond stones must rotate at a speed below 100,000 rpm. Hold the handpiece in the side pen grasp. The junctions of the proximal and buccal and lingual surfaces can be rounded and smoothed with this type of diamond stone. The operator is also advised to use sandpaper disks having fine grit and lubricated with petrolatum or cocoa butter. If a buccal shoulder is present after the preparation is completed it is best to plane and smooth the shoulder with a sharp bin-angle chisel or a convenient Bastian file.

Fig. 255. An isolated tooth may be prepared with one or two instruments. *A*, The small diamond wheel reduces the occlusal as well as the greater bulk of the other accessible areas. *B*, *C*, *D*, The cross-cut fissure bur or the tapered cylinder diamond stone may be used for all surfaces including the mesial and distal areas.

It is foolish to advocate any rigid schedule of instruments and stages for preparing a tooth for a porcelain jacket crown restoration, as so much depends upon the operator's previous training and preferences. However each operator should ask himself the following questions regarding the particular technique he prefers.

1. Does it produce a finished preparation with the desired shape and surface finish?
2. Can it be accomplished within a reasonable period of time?
3. Is the patient's comfort considered with regard to minimising noise, vibration and pain?
4. Is it likely to damage the pulp or supporting structures due to excessive vibration or frictional heat?
5. Is the instrument in full control at all times, or is there danger of slip with resultant damage to the oral structures? (e.g. the use of discs in instruments having considerable inertia.)

Temporary Coverage

It was recognised by the earliest practitioners that a vital tooth prepared for a jacket crown by removing all or most of the natural enamel became sensitive if allowed to remain without some form of temporary protection.

Lo Gro (54) in 1925 covered the finished vital preparation with a coat of cavity varnish such as Copalite. He then placed a gutta percha temporary crown cemented on with a stiff mix of zinc oxide-eugenol or, if the tooth was not sensitive, he suggested that the gutta percha crown be forced into place over the varnished preparation without the use of a cement.

In order to achieve a higher standard of aesthetics for the more demanding patient, he advised the use of a celluloid crown form filled with a mix of silicate cement. This was forced over the lubricated preparation and removed before hardening was completed. It was then trimmed and cemented to place with zinc oxide-eugenol.

Pincus (112) in 1937 advised painting the finished preparation with phenol before placing a temporary crown. Like Le Gro he used a celluloid crown form filled with silicate cement and cemented to place with zinc oxide-eugenol. He warned against setting the temporary crown with silicate cement due to the irritating action of this material. Wheeler (123) issued the same warning the following year.

Both (126) suggested in 1939 that when the preparation was dried it should be protected with warm diluted phenol followed by warm alcohol and chloroform in equal parts and finally coated with Copalite varnish. He claimed that this procedure sealed the dentinal tubules.

The question of cavity medicaments, varnishes, paints, and cements is still a very vexing one. The relative merits of the various materials are still largely an empiric matter each operator having his own particular favourites. What little research of a scientific nature that has been done in this field has been largely inconclusive. On the basis of clinical findings it would seem that the use of a cavity varnish such as Copalite does afford some degree of protection to the exposed dentine. Whether it seals the dentinal tubules is a matter for conjecture, but it certainly renders the tooth a little less sensitive to irritating stimuli. Amongst the proprietary cavity varnishes, Copalite appears to have the advantages of very rapid drying, very low solubility in the mouth, and extremely thin film thickness when used correctly. However clinical experience seems to indicate that it may not resist the penetration of the free acid in silicate cements to a satisfactory degree. Other varnishes may be superior in this respect.

In 1951 Brecker (171) criticised the use of gutta percha in a celluloid crown form as a temporary crown. He said that aside from being unsightly, fluids penetrate such a form and the tooth is subjected to repeated shocks. He considered that silicate cement in a properly filled celluloid crown form was an ideal temporary restoration. However unless this was removed, trimmed, and recemented, the excess silicate would tend to irritate the underlying soft tissues. He did suggest that as an added precaution the crown could be recemented with zinc oxide-eugenol as earlier advocated by Le Gro (54).

Brecker (171) also suggested that cold-cure resin could be used in a resinous crown form. I must say I dislike the clear acrylic crown forms as they are difficult to trim without splitting. Celluloid crown forms are much easier to handle in my experience. However the Surgident Company has marketed a line of coloured acrylic resin temporary crowns which are very aesthetic and fairly simple to adapt.

Most temporary crowns in use today for porcelain jacket crown preparations, both vital and pulpless, are made primarily from acrylic resin. They can be made from proprietary crown forms, such as the clear celluloid or acrylic resin shells, or from the Surgident product which is already coloured and more accurately trimmed. Alternatively, an impression of the area to be restored may be taken in alginate, thiokol rubber, or silicone before the preparation is commenced. This impression is set aside, and when the preparation is complete it is lubricated, and the impression is filled with cold-cure resin of a suitable shade and reinserted. It is allowed to remain in place until the resin becomes leathery in consistency. The impression is removed and placed in warm water to accelerate the polymerisation of the acrylic resin which is then separated from the impression, trimmed and polished, and cemented on the tooth.

In all cases it pays to exercise due care in the construction of a temporary crown. As well as possessing reasonable aesthetics, the temporary restoration should be properly trimmed and contoured so as to maintain the health of the gingival and periodontal tissues. Overextension or undercontour can lead to damage of the gingival tissues, and if the temporary crown must be worn for some weeks there is risk of subsequent permanent gingival recession around the completed porcelain jacket crown.

A word of caution is necessary regarding the cementing of a temporary crown because on occasions it can be embarrassingly difficult to remove. Zinc oxide-eugenol is the material most commonly used, or one of the newer eugenol-free temporary cements. In either case it is advisable to incorporate a little petroleum jelly into the mixture and instead of filling the temporary crown with the cement, it should only be smeared around the gingival area. This will ensure easy removal at the following appointment.

IMPRESSION METHODS

Le Gro (48) stated in 1925 that the word "impression" is used in dentistry to denote a negative likeness of any object, part, or surface, produced by various methods of applying to that object, part or surface one of several kinds of plastic materials that will set by crystallisation or otherwise, in such manner that a positive likeness may be produced from the same.

At the time Le Gro wrote, there were no accurate elastic impression materials available to the profession. The only impression materials then in use were plaster, compound, zinc oxide-eugenol, and wax. The last two materials being unsuitable, a technique evolved by which an impression of the prepared tooth was taken with compound in a copper band.

The whole purpose of impression taking in regard to porcelain jacket crown construction is to produce a working model incorporating a removable die or dies which reproduce the prepared tooth or teeth. The dies need to be removable in order to permit satisfactory buildup and manipulation of the porcelain.

A. Impression of the Prepared Tooth or Teeth

1. The Copper Band - Compound Impression.

This technique has been used in porcelain jacket crown construction for over sixty years and is still widely used. For the fabrication of cast restorations, which does not require an extra hard model and die, compound has generally been superseded by the more accurate and convenient elastic impression materials, i.e. reversible hydrocolloid, thiokol rubber, and silicone rubber. These materials are used in conjunction with the newer densite stones.

However, the construction of the porcelain jacket crown presents an additional problem in that a hard, rigid die is required to permit the fabrication of a wrought platinum foil matrix without any chipping of the fine margins or other damage to the die. Swaging of this platinum matrix, which is desirable to obtain more accurate adaptation against the die, makes further demands on the hardness of the die material. Perhaps with further development (269) it may become possible to electroform a platinum matrix on the surface of a stone die. Until this eventuates, the all-stone die does not appear desirable because even if swaging is abandoned, it is still difficult to fabricate a platinum foil matrix without abrading or chipping the vital shoulder area of the die.

While admitting that a well executed copper band-compound impression is slightly inferior in accuracy to a well executed impression taken with one of the three elastomers previously mentioned, we must ask ourselves just how accurately does a finished porcelain jacket crown fit the die and the prepared tooth? After all, despite swaging, the wrought platinum matrix cannot be perfectly adapted to the die, and in any case this matrix is removed prior to cementation of the crown. Until these sources of inaccuracy have been eliminated, it is foolish to condemn the use of the copper band-compound impression purely on the grounds that the material is slightly less able to record fine surface detail than are the better elastomers.

A great many articles and papers have been written over the years regarding the finer points of copper band-compound impression taking. The first step in the selection and preparation of the copper band. Carey (40) wrote that a tube or band is used rather than a cup for the following reasons;-

When compound is placed in a cup there is danger of air being entrapped, and when the cup is placed over the tooth this air is compressed. When the impression is removed there will be a tendency for this air to expand and distort the impression. It is also generally agreed that the band should be annealed by heating cherry red and plunging into alcohol prior to taking the impression. This ensures that the metal will have no elastic memory which might otherwise distort the impression subsequent to its removal.

There is considerable disagreement as to the size band which should be selected in relation to the size of the prepared tooth. Carey (40), Ewing (184), Keller (187), and Berman (230) advocated a slightly loose fit on the grounds that a little compound should extend slightly beyond the shoulder to show if the shoulder area has been properly recorded. They also stated that too tight a band is difficult to position correctly over the prepared tooth when filled with compound, and it is hard to disagree with this latter opinion. Of course, if a large bulk of compound is allowed to extend well beyond the shoulder this may damage the gingival tissues and also may engage in an undercut area, subsequently tending to produce distortion of the compound in the shoulder area as the impression is withdrawn. However, if care is taken this is seldom a problem.

Wheeler (123) and Clark (127), on the other hand, advocated the use of a tight band. Wheeler claimed that if the band did not fit tightly, the impression of the outline of the shoulder would be faulty and rounded, and the finished crown would have an open margin. This has not been my experience. Clark deliberately selected a band slightly too small, and after annealing, the edge of the band was stretched just sufficiently to pass over the shoulder. He claimed that the flare given the edge of the band in stretching would help prevent its being forced into the tissues. However, there are other methods of achieving this just as effective. The conclusion is then, that the band should slide easily over the shoulder without being so loose as to allow excess compound to flow past the band into the gingival tissues. This degree of fit may be accomplished either by using a stock size band if it is satisfactory, or if not, by stretching a band which is a little too small.

Having selected a suitable band, it must be festooned to the outline of the shoulder. This can first be done approximately by eye. Keller (187) and Berman (230) suggest that a trial impression should be taken with the band filled with wax. The band is then trimmed exactly to this shoulder outline and replaced on the tooth. The level of the free gingival margin is scribed on the band and the labial centre is marked for identification. With the aid of these markings, the band can be correctly repositioned on the tooth when it is filled with compound to take the impression following removal of the wax used in the trial impression.

Berman (230) and Brecker (257) recommended that following festooning, the opposite end of the band should be flanged outwards. This permits a firmer grip on the band and allows finger pressure on the open end without discomfort. It would also tend to stiffen the band, which is now ready to be filled with compound.

McBean (43) and Brecker (257) advocated the use of a high heat compound, but others prefer a low heat material. It seems to be largely a matter of personal choice, although the use of a high heat compound would seem to be indicated where the room temperature is sufficiently high to give rise to possible distortion of a low heat compound impression, especially if it is intended to pack an amalgam die in the impression at this temperature.

Carey (40) suggested the use of dry heat only to soften the compound, claiming that it produced a more accurate impression with sharper outlines. However, Berman (230) and others stated that all compound-filled copper bands should be tempered in water before being placed on the tooth. High fusing compound should be tempered in water at 140°F and low fusing compound at 125°F, he says. Certainly the tempering bath lessens the danger of thermal damage to the pulp of the prepared tooth from the hot compound, but with a little practice most operators acquire the ability to judge the correct temperature of compound prepared by dry heat only.

In connection with the thermal shock produced in copper band-compound impression taking, Squires (60) and others advise first painting the prepared tooth with a varnish, and then applying a lubricant before taking the impression, and this appears to be sound practice.

A rim of compound is seared around the gingival end of the band to ensure positive attachment in this vital region. Softened compound is then forced into the opposite end of the band until it is overfilled. The excess is cut off with a hot instrument and the band is then gently seated. Berman (230) advises that for the first half of the placement, the finger should cover the back end of the band to allow the compound to flow forward in advance of the band. The final half of the placement is done with the fingers on the rim of the band leaving the rear end unobstructed. When the band is fully in position, the finger is again placed across the end of the band and the final compression made.

A short burst of room temperature water is used to cool the band, and it is then left to harden at room temperature. Ewing (154) and others advised chilling the impression with ice-water before removal, but Berman (230) criticised this as producing thermal shock, and on the grounds that excessively chilled compound becomes brittle.

It is important that the impression be removed in a straight line and without squeezing between the fingers, which may cause distortion. This is generally best accomplished by drilling small holes in the copper band, one labial and one lingual, just below the turned flange. A towel clip or other suitable instrument is fitted into these holes to serve as a handle for removal.

The impression is washed and inspected for flaws or lack of sharpness. If faulty, the surface layer of compound may be softened slightly with a needle gas flame and the impression reseated with heavy pressure, allowed to cool, and again removed for inspection.

My own preference is for a method based on the foregoing principles, but differing slightly. After the band has been festooned approximately, annealed, and flanged if desired, a trial impression is taken with compound instead of wax. The final festooning is carried out to a line approximately 0.5m.m. from the impression of the shoulder. The impression is washed, dried, and the surface softened slightly with the needle gas flame as just described. The impression is again seated to its former position and heavy pressure is applied. As only the surface of the compound has been softened, there is no possibility of either pushing any compound much beyond the shoulder, or of forcing the band into the gingival tissues. Also, the final impression is taken at a lower temperature with only a thin layer of softened compound under heavy pressure. This should ensure less setting shrinkage and a more accurate impression in my view.

2. Elastic Impression Materials.

At the present time these comprise reversible (agar-agar) hydrocolloid, irreversible (alginate) hydrocolloid, thiokol (polysulphide) rubber, and silicone rubber. In spite of a degree of success in laboratory trials by some workers, alginate hydrocolloid is still considered to be an unsuitable material for taking impressions of prepared teeth which are to receive porcelain jacket crowns. However, it is quite a suitable material for the overall impression and for an impression of the opposing arch, as will be discussed later.

Of the remaining three materials, agar hydrocolloid has been in use the longest time. Sears (238) used the technique to produce indirect inlays in 1937, but the first reference I was able to find of it being used to obtain impressions of prepared teeth in porcelain jacket crown construction was by Kahn (186) in 1955. He criticised the copper band-compound impression stating that it was potentially inaccurate, liable to injure the gingival tissues, and that the placement of the die in an overall impression introduced still another possible source of error. He stated that it had survived such a long time mainly because of the fear of using stone dies. His criticism of the copper band-compound impression technique seems exaggerated. After all, there are <u>potential</u> sources of error in all techniques.

Kahn takes duplicate tray impressions of the prepared tooth or teeth, and another of the opposing teeth. One working model is poured utilising tapered metal dowel pins (J.M. Ney Co.) so as to produce removable stone dies, and the other is poured as a one piece model. He claims the following advantages:-

(1) The exact gingival contour is conserved to serve as a guide in shaping the jacket crown, so that impingement on the gingival tissue will become impossible.

(2) The immovable die permits the accurate establishment of the contact points. The second cast is cut only if an accident occurs to the other one.

In connection with Kahn's first claim, the gingival area is subsequently trimmed away in the model with the removable dies, and even in the second model some form of gingival retraction would, in nearly all cases, have been carried out prior to taking the impression. Thus it is obvious that the "exact gingival contour" has not been recorded in this technique, and in any case it is not a greatly significant factor in producing a finished crown with correct gingival contour. The desirable contour can be gauged more simply by inspecting similar unprepared teeth on the model or in the mouth.

Sachs (201) used a technique which was essentially similar and he claimed that using it, a jacket crown or crowns could be completed in two chairside appointments. Kahn and Sachs seem somewhat prejudiced, both in their criticism of the copper band-compound impression and in their praise of their own techniques. The fundamental weaknesses in the methods they advocate are the complete reliance on the accuracy of the original impressions, and the use of stone dies. The faults inherent in stone dies have already been referred to. Some of these disadvantages can be overcome by the use of electroformed dies of copper or silver. The properties of various die materials will be more fully discussed in a later section.

It is possible to make use of the above methods by following this procedure, which allows for the use of more durable dies, either of silver amalgam or electroformed by silver or copper plating:-

A tray full-arch impression is taken using either agar hydrocolloid, thiokol rubber, or silicone rubber. A one-piece model is immediately poured in a densite stone. When set, this is prepared so as to have removable stone dies of the prepared teeth, using either a quadrant or full-arch "di-lok" tray (Surgident Ltd.). The dies are carefully trimmed so as to have the "apron area" tapered slightly towards the incisal or occlusal. An individual impression is then taken of each stone die, extending about 3 mm. on to the apron. The impression may be taken in thiokol rubber inside a metal cap, this impression being subsequently silverplated to form the surface of the die, according to Dunworth (272). Alternatively, the impression of the stone die may be taken with compound inside a copper band. This is rather more simple than taking a similar impression in the mouth in that no festooning of the band is necessary . The die must be thoroughly lubricated before taking the impression.

The compound impression of the stone die gives a somewhat wider choice of die materials in that either a silver amalgam die may be packed in it, or it may be copper plated.

The dies, complete with suitable tapered root extensions, are finished and the stone model, with its original stone dies, is re-assembled. A tray impression is taken of this model with thiokol rubber, this material having a stiffer consistency when set than the other elastomers. This impression is removed and the new dies are carefully placed in it in their correct positions. The impression is then poured in a densite stone, resulting in a working model having removable dies with metal surfaces.

The advantages of such a method are:-

(1) A saving of chairside time for the patient as a greater proportion of work is carried out in the laboratory.

(2) Escaping from the tedious and time-consuming task of taking individual copper band-compound impressions of several prepared teeth in the mouth.

However, where only one or two teeth are to have porcelain jacket crowns and no other indirect restorations are to be fabricated at the same time, the copper band-compound impression is probably still the method of choice.

Tray impressions of the prepared teeth with elastomers introduce an added difficulty not usually experienced with copper band-compound impressions, namely temporary gingival retraction. The shoulder of the preparation is normally at a level below the free gingival margin and when used in a tray, the elastomers seldom have enough body to displace the soft tissue sufficiently to obtain an adequate impression without assistance.

The retraction of this tissue is normally carried out by placing layers of suitable gauge cotton string in the gingival crevice to pack the tissue aside. The string may be used plain, or it may contain a drug such as 8:100 racemic epinephrine, a powerful vaso-constrictor which tends to inhibit seepage and shrink the tissue slightly. More powerful (but caustic) chemicals may be used with the string such as alum and 4-8% zinc chloride, but care must be taken not to damage the tissue permanently with these materials. Hence if the string has been treated with these materials it must not be left in the gingival crevice more than a few minutes. At the end of this time it should be replaced either with plain string, or one treated with the epinephrine previously mentioned, which is non-caustic.

Sometimes some of the string is left in place while the impression is taken, or it may be entirely removed. There is now available quite a wide range of methods for temporary gingival retraction in impression taking, and each should be used according to the needs of the case. The overriding consideration is to produce the minimal soft tissue damage consistent with achieving sufficient temporary retraction.

B. The Overall Impression

If individual impressions of the prepared teeth have been taken in order to form individual dies, then an overall impression will be needed to incorporate these dies in their correct positions in a working model. Early workers in this field were forced to make use of either compound, plaster, wax, or zinc oxide - eugenol. None of these materials is elastic and so the only way in which they could be used to record undercut areas with a reasonable degree of accuracy was by resorting to tedious sectional impression techniques.

Tanner (113) used a material called dentocoll, presumably either an alginate or agar hydrocolloid, for taking the overall impression in 1937. This impression must have produced a highly inaccurate working model in Tanner's hands, as it was stored 6-8 hours before being poured while dies were being fabricated. We now know that it is desirable to pour all elastic impressions as soon as possible if an accurate model is required, so for this reason the overall impression should not be taken until the dies have been finished.

If a soft-bodied material such as agar or alginate hydrocolloid is to be used, then it will be necessary to provide some additional means of steadying the die in this impression while the model is being poured. Some assistance can be provided by embedding pins either in the impression material, or preferably in wax or compound placed around the rim of the tray prior to taking the impression. The sides of the die are attached to these pins with sticky wax. While this method is of some help, it is insufficient alone to ensure the proper relationship of the die in the working model. To accomplish this it is necessary to make use of some form of transfer coping into which the die can be accurately and positively fitted.

The transfer coping should have a suitably shaped outer surface to provide for adequate fixation in the impression material. These transfer copings need not be elaborate. It is my view that cast metal transfer copings, while being excellent for the purpose, are tedious to construct and possess no particular advantage.

Iwansson (122) in 1937 recommended the use of a transfer coping made on the die of tinfoil covered by a reinforcing layer of zinc phosphate cement which is roughened to afford a grip for the impression material. A modern improvement, so far as strength is concerned, is the use of cold cure acrylic resin as a substitute for the zinc phosphate cement. Sacchi and Paffenbarger (196) in 1957 suggested the use of a wax transfer coping in conjunction with a hydrocolloid overall impression, but wax is far too soft and plastic a material for this purpose, and compound serves better.

With heavy or medium-bodied grades of thiokol or silicone rubber, transfer copings are not necessary as those materials will hold the die firmly, especially if the pins and sticky wax previously mentioned are also used to help steady the die.

When pouring the model a slightly more fluid mix of densite stone than that recommended by the manufacturer should be used. This will still have more than sufficient accuracy, without the need for more than very gentle vibration to secure adequate flow of the stone. In this way there is less risk of the die being incorrectly located in the subsequent working model.

C. Impression of the Opposing Teeth

As previously mentioned, in a few cases an anterior porcelain jacket crown will have no occlusion with the opposing teeth, and in such cases a record of the teeth in the opposing arch will be unnecessary. However, in most cases there will be occlusion of the finished crown with some teeth in the opposing arch and in order to obtain a guide to this for use in building up the porcelain, an impression of all or part of the opposing arch is usually taken.

I am against the use of crude "squash bite" methods of recording the occlusion and surfaces of the opposing teeth in porcelain jacket crown construction. If there is any occlusion at all, it is my firm opinion that full arch impressions should be taken both for the working model and for the opposing arch, even if only one crown is to be constructed.

Models of only a section of each arch give a most inadequate picture of the general oral condition and of the patient's occlusion.

The study model of the opposing arch taken at the examination and diagnosis stage usually serves the purpose perfectly well. If a new model is required, then an impression of the arch with any of the elastomers will be suitable, alginate hydrocolloid being the most convenient.

D. <u>Relating the Models</u>

Where sufficient teeth are present in both arches, the centric relation is obvious and is to be left undisturbed, it is often more convenient not to mount the models in an articulator but to relate them in the hand. Using the cuspal inclines as a guide, the models can readily be moved into lateral and protrusive positions in order to simplify buildup and adjustment of the crowns.

Where a more elaborate restoration is being undertaken utilising multiple porcelain jacket crowns, and where the occlusion is not obvious or is to be changed, it may be necessary to make use of a face bow record, possibly with hinge axis registration, a fully adjustable articulator, and centric, lateral, and protrusive records. Such complex cases are, happily, not too common as they introduce innumerable possibilities for error.

All indirect (and direct) techniques for the fabrication of inlays, crowns, or bridges introduce the possibility of errors. A porcelain jacket crown when completed will fail to fit the prepared tooth if the original impression and resulting die were inaccurate. The contact points of the crown will be found to be incorrect if the die was not accurately related in the working model. Such errors are difficult to correct in a finished crown, but can often be corrected if the crown is tried in the mouth before it is glazed. For this reason it is strongly urged that this try in stage should not be omitted in the interests of expediency.

DIE MATERIALS AND DIES

The use of a removable die which reproduced the prepared tooth was the natural result of the development of an indirect technique for the fabrication of the porcelain jacket crown. Early dies were made from individual band impressions of prepared tooth. The materials used for the die itself at that time consisted of zinc phosphate and silicate cements, dental stones, and silver or copper amalgam. Subsequently, dies with a copper or silver electrodeposited surface were evolved, and the low-expanding densite stones have produced some improvement in stone dies.

CEMENTS

Zinc phosphate cement was never popular as a die material owing to its brittle nature and low edge strength.

The silicate and silico-phosphate cements appear to be slightly harder and to have better edge strength. After the impression was poured with one of these materials, it was often placed in a makeshift centrifuge mounted on the spindle of a dental polishing lathe, as advocated by Argue (124). This was done in an attempt to ensure dense packing of the cement powder particles and a harder, stronger die, together with the elimination of air bubbles.

Iwansson (122), writing in 1937, preferred the use of a silico-phosphate cement. In fact this particular material (S.S. White Model Kryptex) is the only one of the cements which seems to have persisted as a die material, being advocated by Bartels (216) as late as 1961. One of the more serious disadvantages of the dental cements has been their shrinkage on setting. Gardner (130), in an attempt to partially overcome this, suggested that such dies should be kept in oil when not in actual use.

Iwansson (122) claimed that a Kryptex die would withstand careful swaging, but it is doubtful whether it would withstand swaging sufficient to have any beneficial effect on a platinum matrix. All things considered, the dental cements so far available seem to have little to recommend them as die materials except convenience, and in this latter respect they have been equalled or surpassed by the more recent dental stones.

DENTAL STONES

The earlier hydrocal stones were inclined to crumble, their edge strength was low, and they expanded on setting. Iwansson (122) condemned them as being too brittle in 1937, but Wheeler (123), writing in the following year, stated that he was getting better results with diestone than with any other material. Wheeler's views seem to be at variance with the known physical properties of the material.

The advent of low-expanding densite stones, accurate elastic impression materials, and the desire of many operators to prepare several teeth in the one arch simultaneously, all helped to cause a resurgence in the use of stone as a die material. In use this material is highly accurate and most convenient. Accurate proportioning of the stone, vacuum mixing, and vibrating of the mix into the impression all help to gain the greatest potential in hardness and edge strength from this material. However, it still leaves a good deal to be desired in this respect when compared to a good metal-surfaced die.

Brecker (277) wrote in 1961 that hard stone dies would permit swaging, but as with cement dies, the swaging would need to be so gentle as to have little noticeable effect upon the platinum matrix.

AMALGAMS

Silver and copper amalgams have been in use for many years as die materials. Le Gro (49) concluded in 1925 that amalgam, either silver or copper, was the most dependable material then available, and that the only objection to its use was that it took six to twelve hours to set, and thus required an additional appointment with the patient in order to obtain an impression for a working model in which to seat the die.

Bastian (35) cautioned in 1923 that an amalgam die should be well condensed, otherwise it may easily lose its surface detail and excess mercury could contaminate the platinum. Iwansson (122) in 1937 concluded that the silver amalgam die was decidedly more reliable than either stone or cement. He criticised the use of copper amalgam as a die material on the grounds that it is not as stable as silver amalgam, especially if it is rebased. Further, he said, a preserved copper amalgam die gradually oxidises and gets a black coating making it unpleasant to work with, and also the edge strength is less than that of silver amalgam. He also cautioned against the use of a silver amalgam with too low a silver content, as this type is not sufficiently accurate due to its change in volume on setting.

In connection with this last warning, special silver amalgam alloys, intended for die construction only, have been available for some time. However, their physical properties, unless tested, should be viewed with some suspicion as there may be a much greater volumetric change on setting than is the case with alloys intended for use in the mouth. All things considered, it would appear to be false economy to make use of the cheaper die alloys.

A better method of overcoming the economic question is to make use of a composite die having a preformed root extension of a cheaper metal, such as is the case with Ney dowel pins. In this way the copper band-compound impression need only be filled with silver amalgam sufficient to form an apron of about 3mm. width on the finished die. This renders it unnecessary to invest the impression in order to form an amalgam root extension. As well as saving time and material, this gives better access and vision for packing the amalgam into the impression. The result is a densely packed amalgam die with the maximum in desirable physical properties and which is still not expensive to produce owing to the use of the preformed root extension. Such a die has adequate accuracy for porcelain jacket crown construction and a very hard surface when compared with most other die materials. Its high edge strength permits thorough swaging of a platinum matrix and it can be stored for possible future use without visible deterioration.

In short, it appears to be an ideal material for a porcelain jacket crown die. As stated earlier, its only disadvantage is its long setting time which is of little consequence in most cases.

ELECTROFORMED DIES

Iwansson (122) in 1937 said that a die with particularly even surfaces and considerable durability is the electrolytically produced copper die. He considered that the drawback to its use for jacket crowns was that the root extension needed much care and time to fabricate. There would seem to be little to recommend the copper electroformed die when compared to one of silver amalgam. The copper die takes even longer to fabricate, and the plating process is a source of anxiety as air bubbles or lack of bronzing powder in certain areas are apt to produce voids in the plating. Wax may be used in place of compound to take the band impression for a copper electroformed die, but this material has no particular advantage over compound.

Electrolytically deposited silver has rather more justification for its use than has copper. It is usually deposited against a thiokol or silicone rubber impression, as compound or wax impressions contaminate the silverplating solution (257). In general, the thiokol seems more reliable for this purpose, some of the earlier silicone materials having given trouble as regards silverplating.

Holland (240) used the plating technique described by Silver (241) and Myers (242). The current is set at 10 ma. for each die to be plated and the minimum plating time is four hours. Dies may be plated overnight by reducing the current. Brecker (257) warned that a copper plating tank must not be kept in the same room as a silverplating tank otherwise contamination of the solution may occur. Also, the silverplating tank must be kept covered and in a well-ventilated place as the potassium cyanide fumes are extremely poisonous.

As stated in the earlier section on impressions, the better elastic impression materials are potentially more accurate than is the copper band-compound impression, but it is questionable whether this slight gain in accuracy has any practical significance so far as the porcelain jacket crown is concerned. In any case, the electrodeposition takes some hours to complete, so it is questionable whether the original accuracy of the impression is maintained in the finished electroformed shell.

With all electroformed dies the biggest problem is backing up the plated surface with a core and forming the root extension. Baker (228) used a low fusing bismuth based alloy that melts at 130-140°F (Dr. Ray's low fusing metal). A rod of this material is held against a hot soldering iron and the metal is dripped into the open end of the plated impression until it is slightly overfilled. Baker claimed this method does not cause overheating and consequently does not distort the underlying silver film. He warns that a heated volume of Molotte's metal (melting point 200°F) poured into the impression damages and sometimes partially melts the plating. A root extension is formed by heating the end of a metal preformed dowel and placing it into the low fusing metal where it is held until the metal solidifies again. The impression is then removed and any excess metal trimmed away. Baker omits to mention that shrinkage of the metal on solidification would have probably distorted the electroformed film slightly.

Holland (240) used stone to form the core instead of low fusing metal. This has the advantage of very low setting ~~shrinkage~~ expansion but somewhat lower strength. Also it is more difficult to form a satisfactory root extension when stone is used as the core.

Brecker (257) suggested the use of cold cure acrylic resin or packing silver amalgam into the silverplated impression. Cold cure resin has a fairly high setting shrinkage which makes its use somewhat questionable, although it is excellent in other respects. Brecker quotes Johnson, Philips and Dykema as claiming that silver amalgam adapts itself to the electroformed silver film better than does any other material. It seems rather a remote possibility that silver amalgam can be packed into this thin silver shell, which is backed only by an elastic impression material, without distorting same.

Brecker (257) considers that no electroformed dies are suitable for swaging although, strangely enough, he thinks that stone dies are. He says that swaging often causes a partial indentation of the shoulder or finishing line of an electroformed die because of small voids between the silver film and the core.

It would appear that electroformed dies have several potential sources of error and at their best offer no particular advantage over the amalgam die. Hence it would seem that silver amalgam, one of the oldest materials used for the fabrication of porcelain jacket crown dies, is still unsurpassed.

THE MATRIX

The matrix forms a base on which the porcelain is built up, condensed, carved to shape, and fired. It is usually fabricated from soft pure platinum foil. In most cases the thickness of the foil used is 0.001 inch. Argue (124) preferred a slightly thicker foil (1/750 inch) because it formed a stiffer and more stable base, while Le Gro (49) suggested 0.0005 inch foil in order to achieve a closer fit of the crown. This very thin foil is normally only used for ceramic inlays, and if it is used for the fabrication of a porcelain jacket crown there may be some danger of it warping during the firing shrinkage of the porcelain. Most authorities agree that the 0.001 inch foil is a good compromise between the demands of minimum thickness and reasonable stability.

Early workers adapted the platinum foil on the prepared tooth, but with the advent of a reliable indirect technique this became unnecessary. It is not intended to give a full description of the method of adapting the platinum foil to form the matrix. This information is available in most texts on dental ceramics.

Various methods may be used to form the joint or seam in the matrix. Spalding (11), Avary (18), and Gill (131) preferred to solder the joint. Pure gold or a platinum based solder was used. Bastian (35), Tanner (113), Tylman (232), and Johnson, Phillips and Dykema (264) preferred the tinner's joint, as do most of the more recent writers. Le Gro (49) and Cohen (156) concluded that both were equally suitable, but that the tinner's joint was more simple to execute and saved time. Argue (24) preferred to form the joint by fusing porcelain across the seam, but this is a tedious method and the foil may distort slightly as the porcelain shrinks during firing.

There are four thicknesses of foil in the tinner's joint, which makes it probably a little thicker than a soldered joint, but this is not of any great consequence, except in the shoulder region. Here it is possible to use a simple butt or lap joint without solder, the matrix being held together above and below this region by either a tinner's joint or soldered joint. This shoulder joint may be formed by cutting a section out of the foil while the rest of the joint is being formed, or by grinding this section of the joint down afterwards. The former method is to be preferred, as there is less chance of damaging the underlying die. The incisal part of the seam is generally best formed as a simple lap joint.

Regarding the best position for the joint, Tanner (113) preferred the lingual surface for an upper anterior tooth, but this surface is highly stressed and sometimes it is not possible to reduce the tooth structure as much as would be desirable. Bastian (35) and Cohen (156) suggested that in such circumstances it was desirable to place the joint on the mesial or distal surface. Gill (131), Radermacher (273), and most of the more recent writers advise placing the joint on the mesial or distal surface of an upper anterior tooth routinely, as these surfaces will have a greater thickness of porcelain than the lingual.

The foil is extended past the shoulder to form an apron. Felcher (34) advised that the foil should be trimmed to allow for an apron 1.5 mm. in width and parallel to the shoulder. Radermacher (273) suggested that the width should be 2mm., which is not significantly different.

Early writers advised trimming the foil so that the matrix would stand upright on a flat surface, but the advent of refractory crown stands has made this unnecessary. Having the apron cut parallel to the shoulder also acts as an excellent guide when trimming the porcelain at the shoulder during buildup of the crown.

SWAGING THE MATRIX

This procedure may be carried out in a number of ways and is designed to adapt the foil of the matrix more closely against the die after the joints have been completed and the apron trimmed.

Argue (24) in 1916 used a rather heroic method in which the matrix was swaged on the prepared tooth. After placing the matrix on the tooth, a copper band was held in position by means of a double bow separator and some modelling compound. Pieces of gum camphor were packed in under pressure between the band and the platinum matrix. When packing was complete the whole assembly was removed and then dismantled and the matrix removed from the copper band by burning out the camphor. The method was clumsy, time consuming, unpleasant for the patient, and probably not very effective, so it is not surprising that Argue was its only advocate.

The more conventional method of swaging involves placing the matrix on the die and mounting the die upright in compound in the base of a swaging apparatus such as the S.S. White model. The matrix is covered by a few layers of tissue paper or cotton gauze and the upper half of the swager contains rolled up rubber or plasticine, the latter having a more gentle but less effective action. A couple of heavy blows from a rubber hammer is generally sufficient. It does certainly adapt the platinum more closely to the surface of the die as is often demonstrated by the difficulty experienced in removing the matrix after swaging. If removal should prove difficult, the end of a rod of sticky wax may be melted over the platinum and used as a handle, the wax being subsequently burnt off the platinum in the flame of a bunsen burner.

There has been considerable controversy regarding the relative importance of swaging, and this is related to the question of die materials. Generally speaking, only dies with metal surfaces will withstand the effects of swaging without damage. Hence operators who favour stone or other relatively soft die materials generally deprecate the relative importance of swaging. An exception was Brecker (277), who believed it was possible to swage on a stone die if plasticine was used in the upper part of the swager, however, most authorities believe it is not possible to swage without risk of damage to the shoulder margin of such a die.

Swaging tends to produce wrinkles if the platinum was not very closely adapted to the die in the first place. Pettrow (218) warns that unless burnished flat, these wrinkles are reproduced within the porcelain crown as defined lines of cleavage. If these wrinkles are removed as Pettrow suggests, the metal will be spread again and most of the close adaptation secured by swaging will be lost. It would appear that if swaging is to be used it should be the last stage of adapting the matrix. The platinum will need to have been closely fitted around the die beforehand, otherwise wrinkles will be formed, removal of which is very likely to spoil the close adaptation produced by the swaging.

METAL "REINFORCEMENT" AND THE MATRIX

Before discussing this topic a distinction must be made between the porcelain fused-to-metal jacket crown and the so-called metal reinforced porcelain jacket crown. The former consists primarily of a cast metal jacket which has sufficient bulk and strength to transmit all anticipated forces through to the underlying tooth structure without itself undergoing sufficient deformation to risk damage to the overlying veneer of porcelain which is fused against it and bonded to it.

The latter type of jacket crown consists primarily of porcelain. The "reinforcement" may consist of a thin wrought or cast matrix which is not removed prior to cementation, or it may take the form of perforated foil, mesh, or wire which is embedded in the porcelain, or a combination of these measures. It is this type which is to be discussed, as the former is more properly classified as a cast metal jacket crown with a fused porcelain veneer.

Felcher (129) stated in 1939 "We have always understood that whenever metal is placed in porcelain or in any refractory material, there is a greater tendency to fracture than if the material were used intact". He rightly stated that porcelain does not form a bond with the platinum matrix, which can be easily pulled away from it when firing has been completed. Felcher concluded that there is little to be gained by using perforated iridio-platinum or shells swaged on the dies. However, he modified his views somewhat by 1950 (164), claiming that a method of reinforcing under porcelain had been evolved which was used successfully in many cases. A sheet of 0.002 inch 10% iridio-platinum or 5% ruthenium-platinum was annealed, burnished, and swaged over the platinum matrix. It was invested in a high-temperature refractory and reinforcing accomplished using welding platinum and a gas-oxygen torch. Felcher claimed that the use of this type of reinforcement enabled the use of a shoulderless lingual preparation on selected cases, but his work was not supported by others.

Gardner (130) soldered a strip of round platinum wire around the edge of the platinum matrix for a shoulderless porcelain jacket crown and claimed that it was the secret of strength and durability for this type of crown. While this matrix may have removed the necessity for finishing the porcelain to a fine, brittle feather edge, it is difficult to imagine that it would add anything to the strength of the crown as a whole. He also soldered strips of platinum mesh onto the surface of the matrix in the hope of adding further strength, but this would probably achieve the reverse effect.

Cohen (156) and Brecker (259) discussed methods of reinforcement but drew no conclusions as to their effectiveness, and Megaw (245) considered that it might well weaken the porcelain. Current thought on this matter is that metal foil, wire, or mesh embedded in the porcelain only tends to weaken it, and that leaving the platinum matrix in place does not add significantly to the strength.

The porcelain fused-to-metal jacket crown has so far proved the only really successful means of providing a jacket crown with most of the permanent aesthetics of porcelain with added strength for cases which would be unsuitable for an all porcelain jacket crown. It is significant to note that since the advent of dependable porcelain fused-to-metal techniques there has been little or no mention in the literature of other types of metal "reinforcement" for the porcelain jacket crown.

ELECTROFORMING THE MATRIX

Rogers (269) in 1962 carried out considerable work on the electrodeposition of platinum against the surface of a stone die so as to form a matrix without a seam. If possible, this would be a far more accurate fit than a matrix adapted and swaged from platinum foil.

Research was also carried out to produce a cheaper electroformed matrix of pure nickel, however this material was found to become extremely brittle when firing the porcelain. This was possibly due to oxidation of the metal at elevated temperatures. Plating the nickel with other metals such as rhodium did not solve the problem as the matrix was still prone to crack during the necessary manipulation.

Further work remains to be done on this project, but Rogers was confident that it should eventually be possible to consistently produce an electroformed matrix of pure platinum of the desired thickness.

CONTAMINATION OF THE PLATINUM MATRIX

Pettrow (218) stated that platinum has a natural affinity for a number of contaminating elements, especially in the presence of heat. During fabrication of the matrix, wax and oils are eliminated by flaming over a bunsen burner. Minute traces of metals and other substances which might be present on the surface of the foil are integrated or adsorbed during heating.

He warned that the most prevalent contamination of the platinum is developed during prolonged flaming by the unburnt gases in a yellow or poorly adjusted burner, or in the gaseous inner core of the flame. Adsorbed and integrated contaminations in the platinum matrix are released as gases by dissolution at elevated firing temperatures. These gases penetrate the adjoining porcelain, usually producing excessive porosity on the inner surface of the restoration immediately adjacent to the matrix. General discoloration of the restoration is seldom apparent as a result of foil contamination, he says, except that the cervical border sometimes has a green or brown tint.

Pettrow considered that the most positive method of eliminating platinum foil matrix contamination is accomplished by degassing in the furnace to a temperature slightly higher than the final glaze temperature as a preliminary step. He concluded that this treatment dispels the offensive gases and that the density of the restoration is visibly improved.

Johnson, Phillips, and Dykema (264) agreed substantially with Pettrow and suggested that degassing was especially important if vacuum firing was to be utilised.

COLOUR AND FORM AND THEIR INFLUENCE ON AESTHETICS

Le Gro (50) considered that the best time for shade selection is immediately after the preparation has been made and impressions taken, but Johnson, Phillips, and Dykema (264) prefer to carry out this step before the preparation is commenced, and this is the more generally accepted view.

Normal procedure is for the patient to be seated upright with the teeth approximately at the eye level of the operator. Both teeth and shade guide are kept wet to ensure uniformity. Diffused daylight is generally accepted as the most suitable for shade selection. Gill (74) suggested a northern exposure between 11 a.m. and 2 p.m. as being ideal. Direct sunlight is not really suitable as the eye fatigues very quickly when viewing a light coloured object such as a tooth. As Vehe (28) stated "Because colour is dependent completely on the amount and kind of illumination, a diffused light of an intensity such as the patient is seen in most commonly is the first requirement. It is better that the light be diffused because the different hues of orange cannot be so easily differentiated in direct sunlight". A heavily overcast day with insufficient light makes it equally difficult to differentiate between shades.

Vehe (28) gave a most exhaustive account of the physical and physiological factors involved in colour selection, but Le Gro (50) summed up the position rather well when he said "A long discourse on colour and the phenomena of colour brings little that is of practical value". Klaffenbach (165) drew attention to the impossibility of matching a porcelain jacket crown exactly with an adjacent natural tooth under all lighting conditions, but said that with due care, very close approximation can be obtained. Johnson, Phillips and Dykema (264) recommended that the tooth should be viewed in both daylight and artificial light and from different angles. In this way it is possible to strike a reasonable compromise. It must be clearly understood that it is not possible to exactly match a porcelain jacket crown with an adjacent natural tooth under lights of differing colour temperature because porcelain and natural enamel have different optical properties. A suitable compromise must be found depending upon which type of lighting is most important to that particular patient. In most cases the appearance in diffused daylight will take precedence, but if for instance the patient is a professional actor, the appearance of the crown in incandescent lighting may be more important. Before shade selection, it is advisable to remove all nearby objects whose colour might alter the apparent colour of the tooth by reflection. The most common of these is lipstick and it should be removed.

Selection may be made from a manufacturer's shade guide or one specially baked by the operator using his own porcelain. Le Gro (50) recommended making up a long series of special shade guides - a tedious procedure which is probably now quite unnecessary due to better quality control of the porcelain powders. Early shade guides utilised a separate piece of porcelain for each shade, but the modern trend is to use what is virtually a denture tooth shade guide. The most suitable tooth on the guide is picked out and the porcelain manufacturer supplies a table and detailed instructions how the various shades should be applied and baked to produce a porcelain jacket crown with a similar appearance. It is, of course, possible to obtain intermediate shades by suitable alteration to the table of colours.

Squires (60) wrote that in general there are three fundamental colours in the natural tooth - the first is the shade which is given to the tooth by the blood in the pulp, the second is the dentine colour, and the third is the enamel colour. For practical purposes, he says, we combine the first two and build the bulk of the crown with a porcelain which will combine the dentine colour with such admixture as will give the shade produced by the pulp colour. This means that we use a porcelain which has a slight tinge of orange rather than the simple yellow.

There has been some controversy regarding the relative importance of colour versus form in the final aesthetic result. Vehe (82) and Cohen (157) considered that colour was more important than form. Pilkington (85) thought that both were of equal importance, but Howard (39), Gill (74, 111), and Squires (60) stated that in their opinion form was of far more importance to the harmony of the final result. Howard (39) sums it up rather well when he said "In the matter of appearance of a finished crown, if the tooth form is right and the colour is a bit off, you would have a better looking tooth than if you had the colour right and the tooth form off. Besides, you would have a better condition of the investing tissues in the first case". Of course, it would be desirable to be correct with both the colour and the form. However, the attainment of the desired colour is dependent upon many variables and the best that can be expected is a very close approximation. Form, in contrast, is very much under the control of the operator and it can be modified by reshaping at the try-in stage, before glazing is completed. Colour cannot be more than approximately gauged until the glaze bake has been carried out and the platinum matrix removed.

Gill (74) also drew attention to the effect that the form of the tooth or crown has upon its colour. He stated

"The thicker the tooth labiolingually, the more saturated is the hue; this is especially important at the incisal when constructing the porcelain restoration. When a tooth is irregular it appears more brilliant than one having a smooth surface. The brilliance is produced by highlights reflected from the irregular surface and if these irregularities are not reproduced the crown will appear dull and a darker hue".

Ewing (184) agreed, stating that proper surface anatomy is important to break up and diffuse reflected light. It is generally advisable to make a sketch of the tooth noting any particular surface irregularities, stains, etc. which it is desired to reproduce in the finished crown. Most authorities (50, 60, 74, 81, 264) suggest a small sketch divided into nine squares as the most convenient means of recording these features.

BUILDUP AND FIRING

The basic principles behind these procedures have already been covered in earlier sections. It is advisable to follow the directions of the porcelain manufacturer as regards shade selection, blending, and application of the various porcelain colours in order to closely reproduce the shade guide selected. Experience may dictate minor modifications in this regard as there are variables present:-

(1) The shade guides themselves do vary to some extent.

(2) The porcelain powders may vary slightly from batch to batch, though quality control appears to have improved in recent years.

(3) The thickness of the porcelain has some effect.

(4) The colour and opacity of the cementing medium and of the underlying support exert an influence.

The manufacturer evolves his colour formulae for a porcelain jacket crown of a certain thickness, 1.0 mm. in the case of the Vita Company. In this example, if the porcelain is to be slightly less than 1.0 mm. in thickness, then a slightly darker shade should be selected in order to achieve the same final effect. If the porcelain is to be thicker than 1.0 mm., then the reverse will apply and a slightly lighter shade should be selected.

The colour and opacity of the cement and supporting structure beneath the porcelain have some effect upon the final appearance, unless an opaque base layer of porcelain is used. If a true opaque layer is used, coloured cements cannot be utilised to modify the final appearance. The trend now seems to be towards a semi-opaque base layer which can be slightly influenced by the use of coloured cements, if this is subsequently found to be necessary.

In firing, the manufacturer's advice is usually sound, though some allowance must be made for the vagaries of the particular furnace in use, such as the age of its muffle, variations in the power supply, or possible error in the pyrometer. The whole aim of firing is to produce the desired degree of vitrification in the porcelain, and some minor changes in the manufacturer's time-temperature tables may be required to achieve this end.

THE SHELL OR SLIP FACING METHOD

The first porcelain jacket crowns produced by Land (10) and Spalding (11) utilised a ground porcelain facing, and these facings have been used by some workers up to the present day. A direct method for fabricating this type of crown was advocated by Powell (37) as late as 1924 but is now superseded by the indirect method.

The following brief description of the procedure is taken from a course conducted by Radermacher (273) in 1961:- The facing should be selected slightly larger than the final crown and ground to 1.0 mm. thickness. As there must be a little additional space for porcelain between the facing and the platinum matrix, the labial surface of the prepared tooth should be reduced a total of 1.5 mm. to allow for this, as against approximately 1.0 mm. for the normal type of crown. If the tooth cannot be reduced this amount then this type of crown is contra-indicated, as any attempt to grind the facing to less than 1.0 mm. will result in loss of the dentine colour from the facing and an unpredictable aesthetic result.

The facing is waxed into position against the platinum matrix and a labial plaster key is made. All wax is then removed with carbon tetrachloride. The facing should fit snugly against the labial shoulder otherwise it may shift during firing. The built up crown should be 0.5 mm. longer than the corresponding tooth on the working model to allow for any minor shrinkage.

A thin layer of opaque porcelain is first laid down, vibrated into place, and well condensed. The facing is positioned with the aid of the plaster key. Thin opaque mix is vibrated in to fill the space between the facing and opaque layer on the matrix. The opaque powder is carved away from the incisal region of the facing and this area is filled in with enamel mix and condensed.

Radermacher warns that a shell crown must be preheated very slowly and carefully for at least ten minutes, after which time it is ready for firing. After the first firing, the lingual side is built up with dentine and enamel powders as in a normal porcelain jacket crown and bisque fired. After a try in the mouth and any necessary correction and carving, the crown is glaze fired.

Wood (117) favoured this type of crown on the grounds that it did not require the same degree of skill nor as much time in order to achieve the same effect. If a suitable facing can be selected and it does not have to be ground too thin, the final aesthetic result is probably more predictable, but more often than not difficulties arise from an inability to find a facing of suitable size, shape and colour. Wood suggested the use of a high fusing porcelain to build up the remainder of the crown, but most authorities advocate the use of a low or medium fusing porcelain to avoid overfiring the facing. In all cases the porcelain of the facing and that used to build up the crown must be compatible. That is, a union must be formed between the two during firing, consequently their coefficients of thermal expansion must be very similar.

It is felt that the shell crown has persisted through the years mainly on the supposition that it was easier to fabricate, less time consuming, and that the original colour selection would be positively maintained in the finished crown. However, its use does require more extensive tooth reduction, and it is often not possible to select a facing which has satisfactory size, shape, and colour distribution and which maintains this colour distribution after it has been ground to fit.

The shell crown has always been looked on with some disfavour by the more able porcelain workers. Le Gro (54) considered that in the final aesthetic result it was generally inferior to the hand carved crown. Radermacher (273) considered that it was not as strong as a fully built up, vacuum fired crown. This seems reasonable, as two porcelains of differing composition, fusing range, and coefficient of thermal expansion are being used in the one restoration. Porcelains are naturally selected which have similar coefficients of expansion, but they do not exactly correspond. It is also difficult to flow the porcelain mix between the facing and the matrix and condense it without incorporating tiny air bubbles. Another hazard is encountered in the first firing in that the facing is somewhat prone to shift its position in relation to the platinum matrix.

To sum up, this type of crown has the appearance of simplicity, but in fact it has a more limited range of application, and its strength must be looked upon with some misgivings.

THE ROLE OF THE TECHNICIAN

The early workers in the field of dental porcelain preferred to carry out the laboratory stages in the fabrication of a porcelain jacket crown themselves. Pilkington (81) was against the employment of a technician on the grounds that this led to a lack of individuality in the finished restoration. Gill (74) and Hagen (160) considered that a technician could not visualise the fine anatomic details necessary to produce a really aesthetic restoration. With the development of more accurate study and working models which show the fine surface markings of the teeth this criticism need no longer apply. In any case, the operator can modify the anatomic details of the crown at the try in stage, before returning it to the technician for the glaze bake. Le Gro (54) makes a good point when he suggests that wax may be added to the crown to indicate where and how much porcelain should be added, if this proves necessary.

Johnson, Phillips, and Dykema (264) suggest that it is often advisable to send the actual shade guide selected, as the guides do vary a little in colour. This would seem to be a sensible precaution.

There appears to be no valid reason why the laboratory stages in porcelain jacket crown fabrication should not be entrusted to a technician, provided he or she has received an adequate background in the fundamentals and possesses the requisite manual dexterity. This dexterity is usually only developed and maintained by constant practice, and for this reason a skilled technician who produces many porcelain jacket crowns will generally carry out the laboratory procedures more successfully than will a fully qualified dentist who gets only occasional practice.

THE INFLUENCE OF CROWN CONTOUR ON GINGIVAL HEALTH

There is general agreement regarding the importance of reproducing proper anatomic form in the porcelain jacket crown if the health of the gingival tissues is to be maintained. In this instance theory seems to be far in advance of practice, as porcelain jacket crowns exhibiting poor form and contour, with consequent lowering of gingival health, are all too commonly seen.

Vohe (82) stated that the decided convexity on the labial surfaces of the upper anterior teeth assures conduction of food past sensitive gingival tissues. On the lingual surfaces this is accomplished by the cingulum and marginal ridges around the lingual fossa. In reconstructing these teeth, the mistake is often made of not building in these important features - often the labial surface is left too flat. However, the lingual surface anatomy is the one more often neglected.

The contours of the buccal and lingual surfaces of the posterior teeth also play an important part in protecting the gingivae. The interproximal tissue is protected by a proper contact point or area and by the marginal ridges. The contact point is most nearly perfect in youth - as age advances it is found to be closer to the occlusal surfaces. At the same time it becomes broader and flatter, but as long as there is no pathologic condition present it must be considered physiologic. A close observance of the normal contact point will show that it is located rather near the occlusal surfaces in the posterior teeth and generally in line with the apices of the buccal cusps. In the anterior teeth this point is placed about the centre of the incisal third of the tooth in line with the cutting edges. The greatest importance must be attached to the form of the contact between teeth, and also the interproximal spaces must be sufficiently large to allow for healthy tissues. Vohe also emphasised the need for correct marginal ridges. In the cervical area, he said, the crown should accurately fit down on the shoulder, and the margins between these structures should be as smooth as possible. The porcelain in this area should possess a high glaze and this glaze should not be disturbed.

Wheeler (66) observed that there was a tendency to overbuild in the gingival area and that if this was done the gingival margin would be protected too much. This produced a lack of proper stimulation during mastication and accumulation of food material. Insufficient contour, on the other hand, resulted in recession of the gingival margin and the periodontal membrance. In a later paper (123) he went so far as to state that in the majority of cases there were signs of hyperaemia in the gingival tissues surrounding porcelain jacket crowns. Wheeler found that the normal curvature from the cemento-enamel junction to the crest of convexity is approximately 0.5 mm., and rarely is it as much as 1.0 mm. His method of measurement was to photograph the tooth and use its long axis as a line of reference. He concluded that when this curvature is reproduced in restorative procedures it is usually greatly exaggerated. All the maxillary teeth have similar curvatures approximately the same labially or buccally and lingually. Mandibular posterior teeth have the same cervical curvature buccally as the maxillary teeth, but differ in design on the lingual surfaces, having the crest of curvature about half way between the cemento-enamel junction and the tip of the cusp instead of at the cervical third. Mandibular anterior teeth differ in that they have less curvature on each side. Wheeler also warned against the creation of a double curvature if the shoulder has been terminated short of the cemento-enamel junction.

THE TRY IN STAGE

After the crown has been built up to full contour, bisque fired, and the contact points and occlusion have been adjusted on the working models, it is ready to be tried on the tooth prior to the glaze firing. At this stage the bisque fired porcelain (with the platinum foil still in place) will give only an approximate idea of the final appearance of the finished crown. However, it does permit a further check on the contour, surface detail, contact points, occlusion, and the vitally important cervical area of the crown. The joint between crown and tooth and the curvature of the crown adjacent to the joint may be checked, and modified if necessary.

Le Gro (54) and Radermacher (273) suggested that the apron of platinum be trimmed to within about 0.5 mm. of the shoulder before the crown is tried on the tooth. However, once the occlusion and contacts have been checked, it is advisable to cut the foil flush with the porcelain so that the joint may be checked and the porcelain trimmed if necessary.

Bastian (35) advised a try in at the bisque fired stage in order to avoid any grinding of the porcelain following the final glaze. It is only fair to point out that some grinding of the surface after the glaze bake is quite often necessary in the areas where the crown occludes with the opposing teeth. Also, some slight removal of the high glaze on the labial surface with pumice may improve the aesthetics by reducing unwanted highlights. This treatment is of little consequence so far as the health of the surrounding tissues is concerned, but the glaze must be left intact in the cervical area and on the proximal surfaces.

Le Gro (53) suggested the use of new stones used dry for reducing the porcelain, but most of his contemporaries advised using water with the stones. Le Gro stated that if wet stones were used, a paste of the grindings would be formed which would be packed into the pores of the porcelain and become very difficult to remove prior to the glaze firing. He preferred to use the stones dry and remove the grindings with a blast of compressed air. With the more recent vacuum fired porcelains, the trend is to use dry rubber-based abrasives as these leave a very smooth surface on the porcelain which facilitates the obtaining of a satisfactory glaze without the risk of overfiring.

Some operators, especially some of the more recent ones, have attempted to eliminate the try in stage and complete the glaze bake with only the working models as a guide. The usual result of this procedure is that such crowns have to be ground on their proximal surfaces prior to cementation in order to adjust the contact points. This rough surface attracts food debris and also will produce excessive wear at the contact point of any adjacent natural tooth. It is difficult to disagree with Le Gro (54) who stated that in his opinion the operator who insists upon a try in before the final bake will consistently produce finer finished work.

FINAL STAGES

After the try in has been completed and all necessary adjustments made, the crown is glaze fired and cooled slowly to avoid the development of stresses. The platinum matrix is peeled away from the porcelain and according to Le Gro (53), this is facilitated by the application of a little water. Any sharp edges of porcelain next to the platinum are smoothed with a rubber wheel.

The crown is again tried on the tooth. If a previous try in has been carried out before the glaze firing, correct fit, contact points, and form should be assured. However, it should still be possible to reduce the porcelain if necessary and then use a compatible low fusing glaze, or to add with special low fusing porcelain.

Le Gro (53) stated that the crown may be cemented immediately without etching the inner surface, or fine stones may be used to roughen, or hydrofluoric acid used to etch the surface. He warned that in using the acid it is necessary to melt paraffin wax over the entire glazed outside surface so that the etching will be confined to the inner surface of the crown. This process of acid etching was also mentioned by Spalding (11), Bastian (35), Gill (131), and Radermacher (273).

Hydrofluoric acid is an extremely dangerous material to use or store and its fumes are highly corrosive. For this reason it would seem better practice to roughen the inside surface (if this is desired) with small mounted stones. It is quite probable that roughening the inside surface of a porcelain jacket crown is largely unnecessary, because removal of the platinum foil leaves the surface of the porcelain sufficiently irregular to ensure adequate anchorage for the cement.

CEMENTS

It is not intended to review all the literature concerning dental cements - this would be a subject for a critical review in itself - but some background material is necessary in order to make a rational choice of a suitable material. The dental cements currently available which might be considered even remotely suitable for cementing a porcelain jacket crown comprise zinc oxide, acrylic resin, zinc phosphate, and silicate-zinc phosphate.

Zinc Oxide-Eugenol Cement

Wheeler (123) recommended the use of zinc oxide cement in various colours to seat porcelain jacket crowns because he considered silicate cement to be "irritating when in contact with gum tissue." However, this material has a comparatively low compressive strength, is difficult to remove from the gingival crevice as it does not break cleanly, and is no less soluble than the zinc phosphate cements, according to Peyton et al (236). Though this cement can be produced in various colours it is always opaque.

Acrylic Resin Cement

This material is normally translucent, though it can be produced in opaque forms. It is available in a wide range of colours, though these are not necessarily stable. Peyton et al (236) found no particular advantage in the use of resin cements. The cement powders, they state, are methyl methacrylate polymers in the amount of 33-95% by weight. These are modified by the addition of various inorganic fillers including calcium carbonate, quartz, mica, barium carbonate, and calcium tungstate. The liquids appear to be methyl methacrylate monomer. The authors state that although the shrinkage that occurs during the polymerisation of the resin cement is considerably greater than that noted upon hardening of zinc phosphate cement, this is probably of little practical significance because of the thin cement film. This cement film will expand slightly due to water sorption, which may account in part for the failure of adhesion to tooth structure under oral conditions. They do not mention the very high thermal coefficient of expansion of this material when compared to that of tooth structure.

Although completely polymerised pure methyl methacrylate resin is quite insoluble in water, the resin cements possess an average solubility and disintegration approximately the same as the maximum allowed by A.D.A. Specification No. 8 for zinc phosphate cements. They attribute this to the catalysts, promoters, mineral fillers, and residual monomer present in the resin materials. Compressive strength is similar to that of zinc phosphate cement, but they state that the resin can be formulated to develop thinner films than any of the certified zinc phosphate cements.

Like the zinc phosphate cements, the resin cements exhibit no true adhesion under oral conditions, and the retention of a restoration is accomplished through the mechanical interlocking into irregularities of the tooth and restoration. The problems of colour stability and pulp reaction with the resin cements they reported as being similar to those experienced with the direct filling resins. Johnson, Phillips, and Dykema (264) made the additional point that if a resin cement is used, the gingival excess is very difficult to remove. It would seem abundantly clear that resin cements have little to recommend them in the field of porcelain jacket crowns.

Zinc Phosphate Cement

Peyton et al (236) stated that the terms "crown and bridge cement" and "zinc oxyphosphate cement" have also been used to designate this type of cement. They considered the latter term to be incorrect as there is no evidence that the oxyphosphate forms during the reaction.

Zinc phosphate cement is available in a range of colours, but is invariably opaque. It has been claimed (127) that if a porcelain jacket crown is off shade this can often be corrected by the use of a suitable shade of the cement, however, only corrections of a very minor nature are usually successful. Bastian (151) suggested the trial of different shades of zinc phosphate cement mixed with glycerine before final cementation of the jacket. He later (243) suggested that the glycerine should be diluted with water as the glycerine alone is irritating on a sensitive preparation. There seems no reason why the cement powder should not be mixed with water alone, which greatly simplifies cleaning all traces of the trial mix out of the crown and off the prepared tooth.

Bastian (151) stated that zinc phosphate cement is preferred to silicate because it gives better support to the jacket. This seems hard to reconcile with the fact that silicate cement has a compressive strength approximately double that of zinc phosphate cement (236). Silicate cement is not normally used as a cementing medium for fabricated restorations, probably because of the large particle size of the powder which is adopted for maximum translucency. Silicate-zinc phosphate cements, such as S.S. White Kryptex, resemble silicate cements in general behaviour and physical properties. Their principal difference is that translucency has been sacrificed in favour of finer grain structure and hence finer film thickness.

A thicker mix of cement exhibits lower solubility and disintegration than does a thin mix. This thicker mix, however, will have a greater film thickness if the restoration is seated with the same force. Therefore a balance must be struck so that the cement is mixed as thick as possible consistent with proper seating of the restoration.

Peyton et al (236) warn that any attempt to draw practical conclusions regarding the comparative solubility of zinc phosphate and silicate cements from A.D.A. Specifications Nos. 8 and 9 will lead to possible error as the tests do not necessarily resemble oral conditions. Certainly, as restorative materials, silicate and silicate-zinc phosphate cements exhibit better resistance to solubility and disintegration in the mouth than does zinc phosphate cement. As silicate-zinc phosphate cement also has a considerably higher compressive strength and superior translucency when compared to zinc phosphate cement, it would appear to be a generally superior material to use for cementing a porcelain jacket crown or other restoration where film thickness is not quite so critical as it would be, for instance, in the case of an accurately-fitting cast gold full veneer crown.

Silicate-Zinc Phosphate Cements

Peyton et al (236) state that the silicate-zinc phosphate cements are a hybrid type resulting from the combination of zinc phosphate and silicate cement powders, and the cements are sometimes referred to as zinc silicates. The powder contains a high percentage of silicate to which is added varying amounts of zinc and magnesium oxides, which are the principal components of zinc phosphate cement. These powders may be mechanically mixed or fused together, but they say the fusing appears to result in a cement showing certain superior properties.

Skinner and Phillips (253) stated "Their manipulative characteristics, such as working time and film thickness, are somewhat inferior to those of a zinc phosphate cement, but in terms of strength and solubility they are probably superior". The latter part of this statement appears to be opinion, as no figures were produced to substantiate it.

Paffenbarger et al (108) in 1933 gave the following comparison between the compressive strengths of the best zinc phosphate examined, and S.S. White Kryptex, which is probably the best known silicate-zinc phosphate cement.

	After Storage in distilled water 6 months	After Storage in liquid petrolatum (U.S.P.) 6 months
Best zinc phosphate	13,000 psi.	14,500 psi.
S.S. White Kryptex	19,000 psi.	16,000 psi.

These authors carried out further tests the following year which substantiated the above results and in addition they concluded that the disintegration of Kryptex does not seem to be greatly different from that of a good zinc phosphate cement.

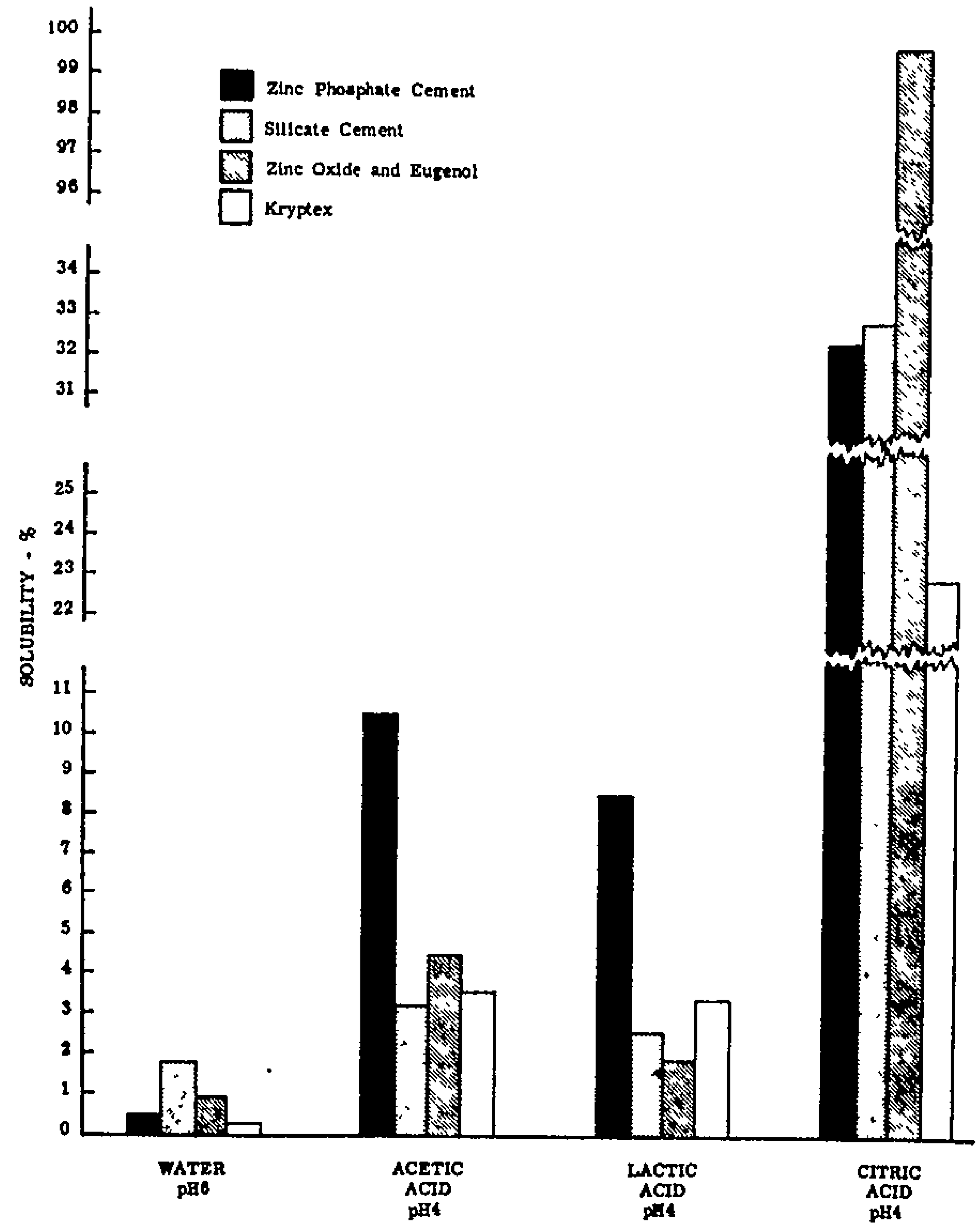


Fig. 15–3. Comparison of various cementing mediums in different solutions after immersion for seven days. The solutions were changed each day. "Kryptex" is the trade name for a combination silicate-zinc phosphate cement.

Reproduced From Reference (251), chapter 15, page 255

So far as film thickness is concerned, Kryptex has, or did have, larger powder particles than those of the better zinc phosphate powders. This was apparently done in the interests of greater translucency, and in any case the small space created by the removal of the platinum matrix from a porcelain jacket crown makes the film thickness less critical. Recently the manufacturers of S.S. White Kryptex claim to have further improved the product, especially in regard to particle size and consequently film thickness, but to date nothing appears to have been published on the subject, and the cement is not yet available in this country (June 1963).

From the foregoing it seems apparent that, at the present time, the only dental cements suitable for placing a porcelain jacket crown appear to be either zinc phosphate or silicate-zinc phosphate. So far as aesthetics is concerned, if the porcelain is thin then the more translucent silicate-zinc phosphate usually produces a more acceptable appearance. When the porcelain is thicker, neither has the advantage unless it is desired to alter the apparent colour of the porcelain, in which case the opaque zinc phosphate is usually more effective. If the butt joint between crown and tooth structure subsequently becomes visible due to gingival recession, a cement line of silicate-zinc phosphate is less obvious than one of zinc phosphate cement.

* Since this was written, zinc phosphate cements have been formulated with film thicknesses half their former value, and if so, zinc phosphate may still have an advantage for the placement of <u>highly</u> <u>accurate</u> cast restorations.

Silicate-zinc phosphate has a higher compressive strength than zinc phosphate, but little appears to be known regarding the relative rates of solubility and disintegration of the two types of cement in the mouth. This situation appears to have arisen because of a difficulty in evolving suitable laboratory tests to evaluate these properties. Clinical observation seems to favour the silicate-zinc phosphate in this regard, but this cannot be regarded as definite. Silicate-zinc phosphate cements usually contain a fluoride which should act as a caries inhibiting agent and if, as has been claimed, the film thickness now compares favourably with that of the zinc phosphate cements, then silicate-zinc phosphate would appear to have the advantage for the placement of both ceramic and cast metal restorations.* See note opposite

Both of these cements are somewhat irritating to the pulp and Bastian (35), Ewing (184), and most other authorities suggest coating the prepared tooth with a cavity varnish as at least partial protection.

APPLYING THE CEMENT

The cement should be carefully mixed on a cool slab (temperature just above the dew-point of the room) to the desired consistency, which is the maximum viscosity consistent with reasonable working time and the ability of the cement to flow sufficiently to permit proper seating of the crown. It should be remembered that, unlike the case of a metal restoration, heavy seating pressure cannot be applied to a porcelain jacket crown without the risk of fracture, according to Roche (161).

A dry field must be maintained during placement of the crown and while the cement sets. Where there is danger of gingival seepage, it is desirable to apply rubber dam if this can be done.

Brecker (171) suggested that the crown should not be filled with cement but should be lined with the mix and carefully rotated over the preparation, until seated. Gardner (130), Ewing (184), and Bartels (195) on the other hand suggested that the crown should be filled and the tooth covered with cement so as to avoid trapping air bubbles. This seems the more rational approach.

Le Gro (54) advised that before applying the cement the glazed surface of the crown in the vicinity of the shoulder be lightly oiled so that when the crown has been cemented, the excess may be easily removed from beneath the gingival margin. Such a procedure is quite unnecessary as the cement does not adhere to polished or glazed surfaces to any extent, and the oil is likely to find its way onto the inside surface of the crown.

After the cement has set the gingival excess is removed with scalers and as an added protection for the freshly set cement a coat of varnish may be applied over the butt joint between crown and tooth.

Brecker (171) sounds a word of caution regarding the cementation of several adjacent crowns. Each such crown can be moved very slightly on its prepared tooth after the platinum matrix has been removed. Thus, if one crown is cemented it may not then be possible to seat the adjacent one as the first has been cemented in a position slightly lateral to that intended. He suggested two means for overcoming this problem.

(1) All the crowns can be seated using the same mix of of cement. This, as he explained, cannot be done with more than three crowns.

(2) The crowns can be placed on the teeth without cement and then removed and cemented one, two, or three at a time while the others remain in place.

OCCLUSION AND THE PORCELAIN JACKET CROWN

The necessity of adjusting the crown to the existing occlusion immediately following cementation has been mentioned by just about every writer on the subject. There must obviously be no occlusal interference by the crown during any functional excursions. This may be checked by means of inspection, carbon paper markings, thin wax registrations etc., and normally presents no great problem.

What controversy there is is centred around what may happen in the years following placement of a porcelain jacket crown. Referring back to page 87, fused porcelain is very much harder than either enamel, dentine, or gold alloys. However, not enough is stated about these hardness tests. For instance, Klaffenbach (133) was of the opinion that a Brinell test was unsuited to a material such as porcelain. Again, it is not stated whether the tests were carried out on glazed or unglazed porcelain and what would be the difference between the two.

The abrasive qualities of dental porcelains are not really well understood. Semmelman (250) in 1962 stated that at present we have no standard abrasion test for porcelain or porcelain teeth, and that any dental abrasion test development is expected to be complicated by diet effects. The surface finish on the porcelain must be a factor, but once again, very little is known of a scientific nature.

Though proven facts are few, this has had no inhibiting effect upon the number of conclusions drawn by clinical writers. Sayre (138) stated that contact with highly glazed porcelain causes almost no wear or abrasion upon human enamel, but Ewing (184) advised that the high glaze should be removed from the occlusal or lingual surface, "for such a high glaze will wear and abrade natural tooth structure". Such contradictory statements on this topic are not uncommon in the literature.

An ideal situation would be one where the porcelain jacket crown did not itself exhibit undue wear, but produced just sufficient abrasion of the opposing contacting surface (whether natural enamel or a substitute material) to avoid development of a traumatic occlusion. The hardness of porcelain being what it is, undue wear of the crown is unlikely to take place, but the maintenance of correct rates of abrasion of the opposing surfaces remains a problem. There are many complicating factors, such as the rate at which natural teeth ground out of occlusion tend to erupt. This appears to vary considerably with individuals, age having some apparent influence.

The consensus of opinion is that a glazed porcelain surface will not abrade the opposing surfaces at a sufficient rate and that this may produce trauma leading to either fracture of the crown or a breakdown in the supporting structures of the involved teeth. Most writers advise removing the glaze from the occluding surfaces of the crown with either a fine stone or a suitable rubber wheel in order to produce a moderately abrasive surface on the porcelain. The use of a coarse stone, especially on air fired porcelain, produces a rough surface which is annoying to the patient and which appears to abrade the opposing natural enamel too rapidly. Conod (234) advised that areas of unsupported porcelain in a jacket crown (for instance, the incisal and lateral portions of an upper anterior crown where there is a normal overbite) should be relieved slightly from the occlusion in order to minimise the risk of fracture, and this would seem to be a sensible precaution.

As Roche (161) pointed out, a special case arises when a porcelain jacket crown is opposed by other porcelain jacket crowns. He warned that removal of the glaze in this situation might not serve to produce sufficient mutual attrition, and also the roughened surfaces will tend to repolish themselves. He suggested that in these cases it would seem advisable either to re-roughen the surface of the porcelain as necessary or to adjust the occlusion from time to time. It would seem a wise precaution to periodically check the occlusion in all cases involving porcelain jacket crowns in order to avoid possible development of trauma. Roche (161) suggested that this routine be carried out annually.

So little experimental work has been carried out on this section concerning the relation of the porcelain jacket crown in occlusion that it is difficult to establish a basis from which to review the literature, which up to the present time has consisted almost solely of opinion based on clinical experience.

THE PROBLEM OF BREAKAGE

Dental porcelain is a brittle material in thin sections. Aside from breakage due to some accidental facial impact, fracture of the restoration may be caused by:-

1. Poor diagnosis in applying this restoration to an unsuitable case.
2. Incorrect preparation of the tooth.
3. Inaccurate dies and models.
4. Mishandling the porcelain during buildup or firing.
5. A crown of grossly uneven thickness.
6. Incorrect cementing procedure.
7. Lack of occlusal harmony, either at the time of placement or developed subsequently.

All of these potential causes of failure have previously been discussed at some length under their respective headings. Saklad (197) developed a dye penetration test for detecting flaws in the finished crown prior to its cementation, but as the dye is only absorbed into flaws opening onto the surface of the porcelain, the test is a rather restricted one and its clinical value questionable.

COMPARISON WITH OTHER FULL COVERAGE RESTORATIONS

One of the chief advantages possessed by the porcelain jacket crown as a restoration is its natural appearance. No material other than porcelain has so far permitted such natural effects coupled with a fair expectation of permanence. In the case of teeth possessing vital pulps, other full coverage restorations available are:-

1. The all-acrylic jacket crown.
2. The cast gold veneer crown with acrylic resin or cemented porcelain facing.
3. The porcelain fused-to-metal veneer crown.

The all-acrylic jacket crown has such serious shortcomings, previously discussed, that it is suitable only as a relatively temporary restoration. The cast gold veneer crown with acrylic resin or cemented porcelain facing possesses serious aesthetic shortcomings in that some gold is usually visible labially, and the full metal lingual surface causes a loss in translucency resulting in a "dead" appearance in the incisal third of the crown.

The porcelain fused-to-metal veneer crown is a comparative newcomer with great possibilities, although to date it cannot be said to have completely displaced the all-porcelain crown. The metal used in its fabrication makes it an extremely expensive restoration to produce, and a labial tooth reduction of at least 1.5 mm. is necessary to ensure adequate thickness. Unlike the previously mentioned veneer crowns, it is often possible to allow the incisal portion of the restoration to consist entirely of porcelain, which allows far greater aesthetic possibilities than would otherwise be the case. One of the chief advantages of this type of crown is the possibility of using it for cases with an unfavourable occlusion, or where insufficient tooth reduction on the occluding surfaces is possible to permit the use of porcelain with safety. In such areas as these the crown may consist entirely of metal without any great aesthetic disadvantage. In cases where labial reduction of the tooth is necessarily restricted and the preparation and occlusion are otherwise suitable, the all-porcelain crown will still have a considerable aesthetic advantage. This is particularly so with respect to the upper and lower incisor teeth.

With pulpless teeth, the choice of restoration is a little more varied. A core of some description may be constructed and any of those crowns previously mentioned placed over it in much the same way as for a tooth with a vital pulp. Alternatively, this core may be an integral part of the crown, that is, it may be a post crown.

In this category, one of the best-known types is the Davis crown. This restoration has a long history and is still in use to some extent. It consists of a stock all-porcelain crown with a post-hole in its base. The base of the crown is adapted to the root face of the prepared tooth and a post with a cast gold diaphragm is constructed to fill the intervening slight space between crown and root face. The fabrication of a satisfactory crown by this method is tedious, and only a limited range of shapes, sizes, and shades is available. In addition, these stock crowns are only produced in air fired porcelain. By the time the stock crown has been adapted to the root face, the post-hole is sometimes too short to provide proper support and retention for the crown, which subsequently may lead to fracture or dislodgment. It is difficult to produce one of these crowns without showing a thin collar of gold at the gingival, which leaves something to be desired in the matter of appearance.

THE PORCELAIN JACKET CROWN AS AN ABUTMENT

The all-porcelain jacket crown has never been a success as an abutment for fixed bridgework because of the stresses involved, and the coping type of bridge utilising porcelain jacket crowns cemented over a metal under-structure has now been superseded by porcelain fused-to-metal techniques.

As an abutment restoration to be used in conjunction with a clasp retained removable partial denture, an all-porcelain jacket crown would never be the restoration of choice, but sometimes the situation arises where one is already in place. In such a case, if the crown is of adequate thickness and placed over a sound preparation it could conceivably perform perfectly well as an abutment restoration. However, should fracture subsequently occur, it becomes quite a difficult task to fabricate a more suitable replacement which is correctly adapted to the existing partial denture. A more prudent course would be to replace the existing porcelain jacket crown with a more suitable restoration before constructing such a denture.

SUMMARY

An attempt has been made to review the literature concerning the porcelain jacket crown under convenient headings. There has naturally been some overlapping of the sections and there are obvious gaps in the basic knowledge to which answers will no doubt be found in the future.

The porcelain jacket crown has a history of over sixty years and has served as a fine restoration for this extended period of time. With the recent development of porcelain fused-to-metal techniques, its field of application has been narrowed somewhat, but it has not yet been superseded, and its aesthetic potential remains unsurpassed by any other full coverage restoration.

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