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ACCURACY OF FOUR ELASTIC IMPRESSION MATERIALS

LOKUKANKANANGE CHARITH LASANTHA PEIRIS,
B.D.S. (Sri Lanka)

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OF SYDNEY
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Thesis submitted to the University of Sydney in partial fulfillment of the requirements for the degree of Master of Dental Science.

Department of Operative Dentistry
University of Sydney
September 1985
THIS THESIS IS DEDICATED TO MY LOVING PARENTS
ACKNOWLEDGEMENTS

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INTRODUCTION

The purpose of an impression material is to record the dimensions of teeth and their surrounding oral structures in their correct relationships. A material in its soft state is placed against the oral tissues and allowed to set, which gives a negative reproduction. A positive reproduction referred to as either a model or cast is obtained by pouring dental stone into this negative reproduction achieved by an impression. Fabrication of inlays, crowns and fixed prostheses are carried out on these casts and therefore the ultimate accuracy and the fit of the restorations is highly dependant on the ability of an impression material to record minute details and form of a preparation.

Beeswax can be softened in hot water and used to register an impression of the teeth. But the material distorts on removal from undercut areas, is dimensionally unstable and most importantly it is not capable of registering fine detail. Literature records that the year 1756 was the first time that plaster models were made from sectional wax impressions of the mouth (Craig 1980). Almost 90 years later, plaster of paris and then modelling compound came to be used as dental impression materials (Peyton 1968). Over the next few years, these two materials were refined, improved, and were used unchallenged until the mid-1920s. When used in undercut areas, compound distorts permanently
on removal, whereas plaster of paris fractures; therefore, to get over these problems a material with elastic properties was needed.

Finally the breakthrough came in 1925 when the jelly-like substance agar, extracted from seaweed, was made use of to make a hydrocolloid material. The credit for using this hydrocolloid as an impression material goes to Alponze Poller (Phillips 1954). It was a great contribution to clinical dentistry. However, satisfactory techniques for its use in Operative Dentistry were developed by A.W. Sears in 1937, when he utilized reversible hydrocolloid to construct inlays, crowns and bridges. The indirect technique became increasingly popular among dentists. Skinner and Kern (1938) were the first to carry out investigations on hydrocolloids which later resulted in the standard specifications for hydrocolloid impression materials.

When the Second World War intervened, the supply of agar for dental use ceased and this led to the search for alternate materials. Another material derived from seaweed and having a salt of alginic acid became available. The powder when mixed with water formed an elastic impression material which however had irreversible properties. This material was very easy to handle and also had some superior qualities (Schoonover and Dickson 1943).
Both agar material and alginate lose water from its surface, thereby showing dimensional change and if dental stone is not poured immediately, the accuracy of the casts cannot be relied upon (Skinner et al 1950).

The 1950s was another important era in the development of new dental impression materials. This time it was the introduction of mercaptan rubber polymers which had been in use for some time industrially. It was found that when suitably added with fillers these rubber polymers, known commercially as thiokol rubbers formed very strong and stable compounds which had remarkable elastic properties. They were dimensionally stable over a wide range of atmospheric conditions, showed excellent compatibility with gypsum products and were able to be electroplated to produce metal dies (Rosenstiel 1955, Fairhurst et al 1956, Silver 1956, Bell and von Fraunhofer 1975).

About the same time Silicone polymers appeared on the market. They had superior aesthetic, manipulation and cleanliness properties when compared with the Thiokol rubbers. Although the early silicone materials suffered from a number of undesirable properties, these problems have now been largely rectified with the result that there are some very good silicone impression materials available for use at present (Peyton 1968).

The mid-1960s saw the advent of the third basic type of elastic impression materials named polyethers which
is an imine terminated compound. Even though they have better mechanical properties than polysulphides and less dimensional change than the silicones, the two disadvantages are its short working time and high stiffness (Braden et al 1972).

The newest of the dental elastomers is the addition cured silicones. As against polymerisation the addition reaction is devoid of by-products, is efficient and is completed in a relatively short time (Brown 1981).

The accuracy of the agar hydrocolloids and the easy handling properties of the alginates were utilized and introduced in 1980 as the combined Reversible/Irreversible Hydrocolloid system where the former bonds with the latter.
PART A

REVIEW OF LITERATURE
PART A

REVIEW OF LITERATURE

CHAPTER ONE

1.1 REVERSIBLE HYDROCOLLOID

Agar, which is extracted from certain types of seaweed, is a sulfuric ester of a galactan complex having a complex structural formula. When agar is dissolved in water, the particles attract the water molecules and swell in size forming a hydrocolloid. At a certain temperature the liquid state (sol) of the hydrocolloid turns into a semi-solid state called a gel. This temperature, known as the gelation temperature, is between 36°C and 42°C. Phillips (1982) reported that the exact temperature depended upon several factors like the molecular weight, the ratio of agar to other ingredients and also the purity of the agar. In order to return it to the sol state the gel must be heated to a higher temperature, referred to as the liquifying temperature. While Craig (1980) stated that this temperature is between 71°C and 100°C, Phillips (1982) stated that it is between 60°C and 70°C. The difference between the gelation and liquifying temperatures is known as hysteresis. It has been shown that the internal energy of the gel is less than that of the sol (Phillips 1982).

Provided that the agar hydrocolloid is used carefully, with a proper understanding of its physical properties,
it is an excellent elastic impression material of high accuracy in registering fine detail. A typical composition of an agar impression material is as follows (Craig 1983):

<table>
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<tr>
<th>Ingredient</th>
<th>Percentage by weight</th>
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<tr>
<td>Agar</td>
<td>12.5%</td>
</tr>
<tr>
<td>Potassium Sulfate</td>
<td>1.7%</td>
</tr>
<tr>
<td>Borax</td>
<td>0.2%</td>
</tr>
<tr>
<td>Alkyl benzoate</td>
<td>0.1%</td>
</tr>
<tr>
<td>water</td>
<td>85.5%</td>
</tr>
</tbody>
</table>

The hydrocolloids come in two viscosities. The tray type is considerably stiffer than the syringe type. Most tray type agar materials have a permanent deformation of around 1% which is below the required ADA specification. However a reasonable thickness of impression material should be present between the tray and the undercut areas so that compression higher than 10% does not occur, since higher compression results in higher permanent deformation (Craig 1983).

Strength:
The compressive strength of a typical agar material is approximately $8000\, \text{gm/cm}^2$ and the tear strength approximately $700\, \text{gm/cm}^2$. These materials are viscoelastic, therefore the strength properties are time dependant and higher compression and tear strengths occur at higher rates of loading. These properties emphasize the importance of a snap removal of the impression which reduces the possibility of tearing the impression (Craig 1983).
Compatibility with Gypsum:
An important fact to remember is that not all agar hydrocolloid impression materials are compatible with all gypsum products. It has been shown that borax is capable of retarding the setting of the gypsum. Smith et al (1962) reported that a gypsum cast poured from a hydrocolloid impression exhibit a high concentration of residual hemi-hydrate and of syngenite as compared with a surface allowed to set with a glass surface. The surface of such casts are softer. Some brands provide a solution of potassium sulfate to counteract the inhibiting effect of agar and borax. The potassium sulfate accelerates the setting of the dental stone in contact with the agar resulting in a smooth hard surface.

Storage of agar impression in air results in dehydration and storage in water usually causes swelling of the impression. It has been shown that storage in 100% relative humidity results in shrinkage as a result of continued formation of the agar network matrix (Craig 1983).

Eames et al (1978) found that some gypsum products were more compatible with hydrocolloid impression materials than others. They found that the immersion of the impression in a 3% solution of potassium sulfate for 15 minutes improved the surface detail in most gypsum products.
1.2 IRREVERSIBLE HYDROCOLLOID

The origin of the use of irreversible hydrocolloid, better known as alginate, can be traced back to the 1940s when an English chemist, William Wilding, received a patent for the use of 'Algin' - a mucous extract from a brown seaweed (Phillips 1982).

Alginate is a soluble sodium salt of anhydro-beta-d-mannuronic acid (alginic acid). The molecular weight of the alginate compounds may vary widely, depending on the treatment during manufacture. When the molecular weight is high the sol tends to become more viscous.

A typical formula for an alginate is as follows (Phillips 1982):-

<table>
<thead>
<tr>
<th>Component</th>
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<tr>
<td>Potassium alginate</td>
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</tr>
<tr>
<td>Calcium sulfate</td>
<td>16%</td>
</tr>
<tr>
<td>Zinc Oxide</td>
<td>4%</td>
</tr>
<tr>
<td>Potassium titanium fluoride</td>
<td>3%</td>
</tr>
<tr>
<td>Diatomaceous earth</td>
<td>60%</td>
</tr>
<tr>
<td>Sodium phosphate</td>
<td>2%</td>
</tr>
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</table>

The chemical reactions that take place when alginate powder is mixed with water is adequately covered in text books (Phillips 1982, Craig 1980) and will not be repeated here. The final result in this chain of reactions is the formation of an insoluble calcium alginate gel. The fibrils in a so formed gel are assumed to be held together by primary bonds. This differs from the reversible hydrocolloids where the forces are of intermolecular in nature. Nevertheless
the final structures of the two types of gel are similar and they have a common relationship to the surrounding environment, strength and other properties (Phillips 1982).

According to the American Dental Association's specifications, there should be less than 3% permanent deformation when the alginate is compressed 10% for 30 seconds. It should be noted that the properties of alginate varies greatly according to factors such as the water/Powder ratio, temperature and manipulation (Phillips 1982).

Dimensional stability:
Like the reversible hydrocolloids, the alginates lose the accuracy with storage. Storage in water or for that matter in air, results in dimensional change. Craig (1983) reported that alginates shrink even under conditions of 100% relative humidity due to syneresis. Syneresis occurs as a result of continued chemical reaction and forcing out of water from the set material. Therefore it can be said that there is no satisfactory way of storing reversible hydrocolloids and alginates and that pouring of casts should be carried out immediately following the impression procedure.
1.3 POLYSULFIDE RUBBER IMPRESSION MATERIALS:

The base material consists of about 80% low molecular weight organic polymer, containing reactive mercaptan groups and 20% reinforcing agents such as titanium dioxide, zinc sulphate, copper carbonate or silica. The accelerator or catalyst contains a compound that causes the mercaptan groups to react to form a polysulfide rubber. The catalyst is carried by an innert oil such as dibutyl or dioctyl phthalate. The most common catalyst to be used by manufacturers is lead dioxide causing the material to be dark brown in colour. The addition of lead dioxide causes both chain lengthening and cross-linking by oxidation of the \(-\text{SH}\) groups (Braden 1966, Phillips 1982). There are fillers, plasticizers, pigments and deodorizers added to make the material more suited to be used for dental purposes. Dentally they are produced in three viscosities - low, medium and high.

The polymerization reaction is exothermic and the mixing temperature as well as the presence of moisture exert a considerable influence on the reaction (Jorgensen 1956, Phillips 1982). According to Fairhurst \textit{et al} (1956), there is water evolved during the reaction and it is possible that its volatization could affect the dimensional stability.
Dimensional Stability:
During the first 24 hours, the polysulfide rubber shrinks 0.1% to 0.3%. It has been shown that even though the material has set, a flow of between 0.3% to 0.9% can occur in 15 minutes, which would result in the distortion of the impression. According to the consistency of the material, the flexibility values varies from 2% to 20% (Craig 1983).

Polysulfide rubbers have for many years been able to reproduce fine surface detail even lines as narrow as 0.25 mm. These materials have been found to be highly comparable with dental stone (Craig 1983).

Lautenschlager et al (1972) and Inoue et al (1978) showed that elastic deformation is somewhat lower in polysulfides when compared with silicones and polyethers. Even when the material is subjected to a prolonged strain like removing an impression slowly, the elastic recovery is sufficiently quick. They pointed out that pouring of models need not be delayed.

One of the biggest advantages of polysulfides over the agar hydrocolloids is the fact that the tear resistance of polysulfides is about 10 times greater than that of hydrocolloids - (6300 gm/cm). The strength and permanent deformation properties of the polysulfides continue to improve for a number of hours after they are set (Fairhurst 1956, Craig 1983).

Polysulfides are also known as Thiokols or Mercaptan rubbers.
1.4 CONDENSATION POLYMERIZING SILICONES:

The base is a moderately low molecular weight silicone liquid called dimethyl siloxane which has reactive -OH groups. Stiffness is achieved by the addition of reinforcing agents such as silica. The accelerator or catalyst consists of tin octoate and an alkyl silicate such as ortho ethyl silicate. Silicones are available in four consistencies - light bodied, medium or regular, heavy bodied and finally a very high viscosity material usually referred to as a "putty". The concentration of the reinforcing agent varies from 35% in the light bodied to 75% in the putty consistency.

The dimensional change in the first 24 hours after setting is larger than the polysulfides and is due to the evaporation of the alcohol produced in the reaction. It has been shown that a large decrease in dimensional change occurs when the filler content is increased (Braden 1966, Braden 1975, Phillips 1982, Craig 1983).

The permanent deformation of the silicones is lower than that of the polysulfides. It is thought that these lower values are related to the higher cross linking in silicones, which is a three dimensional network. In the putty material the value is 2.2% whereas in the light bodied the value is approximately 1%. The flow values, one hour after setting are also much lower for the silicones than for the polysulfides.
The flexibility of the silicones is also lower (Craig 1983).

Silicones are capable of reproducing fine details. It has been shown that a V shaped groove with a width of 0.025 mm is reproduced with marked clarity. The tear strength is around 4500 gm/cm which is lower than that for polysulfides but considerably higher than values for hydrocolloides (Craig 1983).

1.5 ADDITION POLYMERIZING SILICONES:

The addition cured silicones also come in two pastes - a low molecular weight silicone having terminal vinyl groups, fillers and a chloroplatinic acid catalyst. The second paste contains a low molecular weight silicone with terminal silane hydrogens and fillers for reinforcement. The addition reaction takes place with no by-products being formed (Craig 1983).

One of the most noteworthy improvements of the addition type silicones over the condensation type is the dimensional change and permanent deformation. The value for dimensional change as reported by Craig (1983) is -0.05% for the first 24 hours. Permanent deformation values are 0.07% to 0.16% at the time of removal of the impression. Both these values are the lowest for all rubber impression materials.

Working time is shorter than for the polysulfides and the flexibility is lower than for any other rubber
impression material except polyethers. Due to the
stiffness of the material extra space should be
provided for the impression material when a custom tray
is used. Tissue culture tests on this material has
shown less tissue reaction than the condensation
silicones. These materials are capable of reproducing
lines smaller than 0.025 mm (Craig 1983).

1.6 POLYETHER RUBBER IMPRESSION MATERIAL:
The base is a low molecular weight polyether polymer
containing ethylene imine terminal groups.

The working time is the shortest among all rubber based
impression materials. The permanent deformation is
less than that of the polysulfides but is not as low
as the silicones. These have a less flow than either
the polysulfides or the condensation silicones but
slightly higher than the addition cured silicones. Due
to the low value of flexibility, a 4 mm thickness of the
material between the tray and the teeth is recommended
(Craig 1983).

Braden et al (1972) carried out an extensive investi-
gation on the properties and the behaviour of polyether
impression material. They reported that these materials
have a good dimensional stability in air, but however
they had a high affinity for water. In practice the
dimensional stability in contact with water is affected
by water sorption and by the extraction of water soluble
material present in the polyether, possibly glycol
ethers or polyglycols. Because contact with aqueous media and various humidities is inevitable, susceptibility to such effects is the principal disadvantage of this impression rubber.
CHAPTER TWO
COMPARATIVE STUDIES

2.1 EARLY COMPARATIVE STUDIES

It is reported that the first patent for reversible hydrocolloids was granted in 1927. The article by Sears in 1937 describing the advantages of the use of hydrocolloids resulted in a great awareness among the dental profession, of its remarkable accuracy in the construction of inlays and fixed bridges. One of the finest early articles was published by Thomson in 1953 which includes a comprehensive discussion on hydrocolloids. Thomson concluded that "The accuracy of the fit of the inlay and of other restorations seem incredible".

In the late 1950s, a large number of comparative studies were carried out on the behaviour of rubber impression materials. Schnell and Phillips (1958) studied the dimensional stability of five thiokol rubber impression materials and the effect of certain other variables which influence their accuracy. They concluded that none of these five materials were dimensionally stable and the distortion probably occurred due to the continued curing of the material. Distortion, however, at any time interval, was less than with reversible hydrocolloids.

Jorgensen (1957) studied the properties of ten thiokol
impression materials and found there were great differences between them. The thiokol pastes shrank during polymerisation and continued to do so after they were removed from the mouth. Polysulfides also have been the subject of numerous other investigations (Skinner et al 1955, Fairhurst et al 1956, Sturdevant 1957). These studies revealed that the elastic properties of these materials improved considerably when they were allowed to set longer than the manufacturer's recommendations. The lack of tackiness was not a satisfactory indicator of setting time and that a reduced setting time for most rubber base impressions would be desirable for their use in dentistry.

Two important studies were carried out on the early silicones which need special reference. The first one of these is the investigation by McLean (1958) where he found the silicone rubbers continued to polymerise for long as two weeks after their initial set. They exhibited a mean range of linear contraction at 15 minute set, of 0.04 to 0.27 per cent, and at two weeks storage, 0.36 to 0.82 per cent.

The second major study was by Gilmore et al (1959) on factors affecting the accuracy of silicone impression materials. They studied seven commercially available silicone materials and during the course of their research, even though the formulation of many of the brands were altered by the manufacturers, they observed
that the use of a double mix procedure produced more accurate impressions than a single mix procedure. They concluded that the silicones available at that time showed considerable individual variation in accuracy than the polysulfides.

The view that silicones were more elastic than the polysulfide rubbers even though the latter exhibited greater dimensional stability was shared by Anderson (1958) and Skinner (1958). Skinner thought that the shrinkage was due to the polymerisation process and the volatilization of constituents. He also suggested that the setting reaction of polysulfides produced water and its loss could be the reason for the shrinkage. But Phillips (1959) did not seem to consider that syneresis and imbibition had anything to do with both these two materials.

In a silicone impression material study, Tomlin et al (1958) pointed out that a change in dimension of 0.04 mm in an initial dimension of 10 mm is significant in affecting the fit of a crown. They suggested that models should be poured within four hours. Eberle (1959), Lund et al (1959), suggested that if models from silicone impressions are to be accurate, the pouring should be done within 30 minutes of impression taking.
2.2 The 1960s:

Ten brands of polysulfide materials and four brands of silicone materials were investigated and their physical properties compared favourably with those of agar hydrocolloids. In general, the silicones exhibited less permanent deformation and greater strain than the polysulfides, when tested 5-10 minutes after the beginning of the mix (Miller et al 1960).

The distortion of irreversible hydrocolloid and polysulfide rubber base impressions were studied by Hosoda and Fusayama (1960). Among their findings it was interesting to note that the distortion of polysulfide rubbers caused by the undercuts was hardly evident at the end of one hour when the casts were poured at mouth temperature. This distortion increased markedly with storage time.

Miller and Myers (1962) studied the behaviour of 7 silicone materials and reported that the elastic qualities of all these were satisfactory and the percentage strain and percentage permanent deformation were within the values of the proposed specifications at that time for rubber base impression materials.

The versatility of the polysulfide rubber as an elastic impression material in the construction of inlays, crowns, fixed partial dentures and porcelain jacket crowns is very well described in an article by Duxbury (1963). He reported that improper retraction of the
gingival tissue caused most failures of this impression material.

Custer et al (1964) investigated the accuracy and dimensional stability of a silicone rubber base impression material. During this study, they found that the non-recovery of silicones after setting under compression in a tray is less than 1% compared to approximately 2% for polysulfides and approximately 4% for an irreversible hydrocolloid. The authors reported that in the case of silicones, greater accuracy was obtained in custom trays or with wash techniques than with impressions taken with stock trays. They also firmly believed that the manipulation and techniques for using these materials very definitely affected the accuracy of reproduction. The conclusions of this particular study markedly differs from the study of Myers et al (1959) reported earlier.

By the year 1963, the accuracy of all three materials, namely the reversible hydrocolloids, the silicones and the polysulfides had reached a very high standard of accuracy. However, Hollenback (1963) reported that as the time interval between impression taking and pouring the models increased, the silicones showed greater inaccuracies than the polysulfides.

The dimensional accuracy of casts is almost entirely dependant upon the elastic recovery of the impression material. This recovery is indicated by the percentage
set of the material after it has been strained by a known amount, within a given time. The percentage set of the material can be measured in either compression or tension. Wilson (1966) reported that the compressive strain induced in a material is dependant amongst other things, upon the thickness of the material used. In contrast, the tensile strain induced is not dependant upon the thickness of the material. This means that the performance of a material with a high compression set can be improved by using a thicker section.

A similar study was done by MacPherson et al (1967) measuring the stress strain properties of hydrocolloid and rubber impression materials, in compression and the resistance to tearing. The authors observed that the elastic and plastic properties of agar hydrocolloids, polysulfides and alginates are a function of:

a) the rate at which the materials are deformed
b) the time at which the material is tested
c) consistency of the mix

The Commonwealth Bureau of Dental Standards in Melbourne, Australia, carried out extensive laboratory testing of six elastic impression materials. This was one of the first studies which compared the polyether material. It was shown that the dimensional stability of polyethers was similar to that of polysulfides, but better than that of silicones. The authors recommended that the proposed limit of 0.2% maximum dimensional change
after six hours should be extended to 0.4% at six hours for polysulfides and polyethers and 0.8% at 24 hours for silicones (Chong and Docking 1969).

2.3 The 1970s:

Schwindling (1971) investigated the linear changes of a silicone material over a period of 48 hours and showed that the room temperature at which the material was stored prior to pouring had an effect on the accuracy. It was shown that by controlled pre-heating (after various storage times) more accurate models could be obtained.

A series of polysulfide impressions were taken of a ceramic tooth preparation in a dentoform model to show the influence that coating the preparation with various agents (saliva, separating agent, petroleum jelly) had on the accuracy of the impressions. It was shown that all the surfaces of the dies were significantly larger than the original model. However, it appeared that the presence of various agents did not significantly affect the behaviour of the polysulfide material (Smith 1971).

The effects of a number of variables on the dimensional accuracy of representative polysulfide, silicone and polyether impression materials, under simulated clinical conditions, were studied by Kentwell (1971) using a chrome cobalt die. He found the polysulfide material to be the most accurate and the inaccuracy increased
when the bulk of the impression material was greater. He also found that when impressions were taken using perforated trays the accuracy of dies was less predictable than when using unperforated trays coated with adhesive.

A very interesting investigation was carried out by Lautenschlager et al. (1972) where the recovery of polysulfide base impressions to initial shape was monitored by motion pictures during clinically simulated removals. Analysis of the individual frames of the motion pictures showed that return of portions of the impression material began as soon as the removal process began. The second recovery phase was experienced as soon as the material became completely free of the undercut blocks. The rates of return were dependant on maximum strain incurred, position along the undercut, and rate of removal. It was shown that all the materials tested quickly returned to a shape suitable for accurate casting. The materials were not so rigid that unduly large forces were required for impression removal, nor were they so lax that they could be deformed greatly under the weight of the casting stone.

Braden et al. (1972) studied the physical properties and behaviour of imine-terminated polyether impression material. Although the set polyether material exhibited changes of less than 0.1% during a long period in air, considerable changes occurred when the specimen was
subjected to moisture contamination. When the material was immersed in water, there was an initial expansion and subsequent contraction which corresponded to the initial uptake of water followed by the loss of soluble materials. The authors pointed out that prolonged exposure of polyethers to water should be avoided.

The sources of inaccuracy which can develop during and after the use of elastic impression materials was the subject of analysis by Brown (1973). Experiments were performed on both the hydrocolloid and elastomeric groups. The lead dioxide cured polysulfide and the polyethers were the least affected by the strain accompanying their withdrawal from undercut regions. During storage the polysulfides were the least susceptible to both water absorption and solvent loss whereas the polyether material absorbed water and swelled. It was found that the silicones and the hydrocolloids did not maintain their accuracy during long storage.

Sawyer et al. (1973) and Sawyer et al. (1974) measured casts from seven types of elastic impression materials and like Brown (1973) found the polyether to be most accurate but contrary to Brown's findings, Sawyer et al. found that the accuracy of polyethers was not affected by damp storage. In addition it was demonstrated that measurement of casts produced from the polyethers which were poured one week from the time they were made, varied
only slightly from those poured immediately.

Reisbick (1973) used silicones, polysulfides and agar hydrocolloids at the lowest and highest viscosities likely to be used in dental practice. He found viscosity made no significant differences to accuracy or stability up to one hour for laboratory or clinical preparations. For one hour old impressions polysulfide was most accurate and agar the least.

The permanent deformation after increasing tensile loads for 15 elastomeric impression materials were measured by Kalyonnides (1973). At 10 minutes, silicones ranged from 0.17% to 1.74% while polysulfides ranged from 3.2% to 17.06%. It is interesting to note that both silicones and polyethers were thus superior at 10 minutes, but at 24 hours there was not much of a difference, the polysulfides having improved greatly and the silicones deteriorated slightly during this time.

Stone dies were found to be more accurate than silver-plated ones poured from silicone materials. The polysulfides did not show any difference in accuracy (Cooney 1974).

Henry and Harnist (1974) compared the dimensional accuracy of three polysulfides, four silicones, and a polyether by pouring stone casts of impressions of a silver-plated model and measuring the horizontal dimensional changes between four posts on two ridges.
Polysulfides and the polyether gave positive changes and silicones negative changes.

Hembree and Nunez (1974) noted the discrepancies of gold castings using two polyether materials to take impressions of wet and dry models. The wet models gave greater discrepancies than the dry ones, whether the stone was poured immediately or after one hour.

Sawyer et al (1974) conducted an investigation to determine the comparative accuracy of stone casts poured from nine different elastomeric impression materials. The casts from these impressions were measured in both horizontal and vertical dimensions and mean deviations from the master die were calculated. The most accurate casts were produced from the polyether material and the next most accurate from the silicones.

Stackhouse (1975) compared the accuracy of 14 elastic impression materials by taking impressions of a model composed of natural teeth and stainless steel dies and measuring stone casts poured after different intervals. He found no significant difference in accuracy among the elastomers if models are poured within 30 minutes, but at 24 hours the silicones showed greater change than the polysulfides. The author also found that dies poured immediately to hydrocolloids were not significantly different from those poured to other materials within 30 minutes. It is remarkable to note that even fourth generation casts poured from
polyethers were significantly accurate over a 24 hour period.

Mansfield and Wilson (1975) studied the effect of temperature changes on the dimensional stability of elastic impression materials. Results for the thermal contraction from 32° to 23°C ranged from 0.46% to 0.90%. Contraction due to polymerisation up to 24 hours showed the high viscosity polysulfides and silicones to be the most stable and the low viscosity silicones the least stable.

Up to this time, most of the accuracy studies as well as the comparative studies on elastomers had been restricted to local accuracy only. Differing from the rest, Staufer et al (1976) utilized a metal master model and a metal partial denture to compare impression materials. This method will be reviewed later on in the chapter. The results showed that the polysulfides gave a small isotrophic deformation, hydrocolloids gave a larger displacement in the antero-posterior direction while the polyether and the silicone gave a lateral displacement. The casts with isotropic or lateral displacement were the ones showing the best fit visually.

Braden (1976) reviewed rubber impression materials with regard to dimensional change during and after setting. He showed the chemical differences between the four types of silicone rubber and dealt with the dimensional
behaviour of these and other elastomers. He also suggested that polyolefines and thiol terminated polyoxyalkalene glycols may be future impression materials.

It was shown by Lorren et al (1976) that a greater probability existed for air bubbles to occur on casts produced from silicones than on casts from polysulfides or polyether materials. The reason for this was the relative non-wetting characteristics (high contact angle) between die stones and silicone materials.

Rehberg (1977) has discussed the way in which the impression tray can play a part in the accuracy of the impression material. He measured the flexion of trays under load, their expansion from the warmth of the mouth, and the subsequent changes afterwards. It was shown that too flexible a tray would give distortions unacceptable for a crown.

With the introduction of the new type II or addition type silicones, there were a number of studies to compare its properties. Harcourt (1978) found them to be somewhat stiffer than the thiokol rubbers, while the type I condensation curing silicones were more flexible than either of them. He pointed out the importance of avoiding jiggling movements when removing the tray.

McCabe and Wilson (1978) found that dimensional stability of type II silicones was much better than in the type I materials, the contraction being almost
entirely in the first three minutes after removal and mostly due to cooling to room temperature. Unlike the type I material the heavy bodied type II tended to be slower setting than the light bodied material. This study confirmed earlier authors' views that an extra few minutes should be added to the setting times than what the manufacturers recommend.

The accuracy and stability of impressions made with four types of elastic impression materials was studied by pouring stone casts to the impressions of a stainless steel crown preparation. The range of dimensional error was in the range of 0.11 to 0.45 per cent after 30 minutes and 0.18 to 0.84 per cent after 24 hours. The authors concluded that provided the casts were poured immediately after removal, the stability characteristics of all the materials were similar. But if the pouring was delayed it was shown that addition cured silicones and polyethers were far more stable than condensation silicones. During the first 30 minutes the polysulfides were as accurate as the polyethers, but as time went by they were shown to lose their accuracy (Eames et al 1979a).

The same authors examined how the bulk of the impression material affects the accuracy. Trays were constructed to give 2 mm, 4 mm and 6 mm spacings around a tapered stainless steel die and the average error for all the materials tested was least for the 2 mm thickness and greatest for the 6 mm thickness (Eames et al 1979b).
Polyether and polysulfide materials were compared by Nayyer et al. (1979) by measuring working time, setting time and compression set by American Dental Association specifications and other methods. Their conclusions were a confirmation of already established facts, such as the superior elastic properties of polyethers, the improvement in elastic properties when more time is allowed for setting and the slower setting of polysulfides.

Norling and Reisbick (1979) indicated that when casts are poured from hydrophobic materials, such as the polysulfides and silicones, the surface of casts may not be smooth due to bubble entrapment as a result of poor wetting. On the contrary, hydrocolloids, being hydrophillic, do not give rise to this problem and polyethers have a low wetting angle which is close to hydrocolloids. The study revealed that by adding nonylphenoxy poly (ethyleneoxy) ethanol to polysulfides and silicones, it was possible to reduce the number of bubbles compared with the unmodified material.

2.4 The 1980s:

Engelman (1980) described that if optimum results are to be obtained from hydrocolloids, they should be poured within the first 5 minutes and the casts left to set for one hour at 100% humidity.

In a survey carried out by Shillingburg et al. (1980) on the use of impression materials and techniques used
for cast restorations it was revealed that the most popular material was polysulfides followed by poly-ether and hydrocolloid, with silicone elastomers being the least popular.

After an experimental study, Yeh and Powers (1980) summarized that addition cured silicones have a small dimensional change on setting, low creep, a short working time, moderately high resistance to tearing and are fairly stiff.

McCabe and Storer (1980) performed a comprehensive study of twelve elastomeric impression materials with regards to assessing their suitability for use in producing cast metal restorations. They found that silicones had good elastic properties, but underwent significant dimensional change. Addition cured silicones had greatly improved dimensional stability but poor tear resistance. Polysulfides were found to have good tear resistance, but were visco-elastic. The polyethers possessed a balanced variety of properties, but were relatively rigid when set. The authors also found that the tray material and the thickness of the impression material played an important part in impression accuracy. From the results it was concluded that no material was ideal for all applications and that careful selection should result in satisfactory impressions for any clinical situation.

Two polysulfides (one lead cured and the other non-
lead cured), a condensation silicone, an addition
cured silicone and a polyether material were subjected
to simulated clinical conditions and evaluated for
their accuracy and dimensional stability at various
time intervals (Ciesco et al 1981). All impressions
that were poured immediately and evaluated using a
custom tray and adhesive showed superior results as
compared to those tested without the custom tray.
In rank, the polyethers were the most accurate followed
by addition cured silicones, lead cured polysulfides
and finally condensation silicones.

An almost identical study was carried out by Lacy et al
(1981) but they came out with slightly different
results to the results obtained by Ciesco et al (1981).
These workers found that Polyvinylsiloxane (addition
cured silicones) are the most stable and the accuracy
and consistency were best maintained by the use of
custom tray and adhesive. The polysulfides bonded to
custom trays show a progressive increase in die
diameter with time. Dies produced from polysulfides
over a four day period seem no more or less accurate
than dies produced from condensation silicones. Poly-
ethers were found to be intermediate in stability to
polysulfides or silicone systems. There appears to
be no pronounced differences between single mix and
double mix techniques for polysulfides.

A technique with the aid of a sensitive instrument
called 'holographic interferometer' was described by
Mincham and others in 1981 to measure the changes in dimensions of elastomeric impression materials. The authors claim that in this preliminary investigation the results obtained compared favourably with results obtained by other techniques.

A simple accuracy study was carried out by Brown (1981) comparing the polysulfides, both types of silicones and the polyethers. He noted that -

a) the polysulfide showed the greatest overall shrinkage due to both polymerization and storage;

b) the type I silicone showed less overall shrinkage than the polysulfide due to both polymerization and storage;

c) polyether showed the greatest amount of thermal contraction but the effect of polymerization and subsequent storage produced models which was seen to be getting progressively smaller as the storage time increased. This confirms that the polyethers absorb water during storage.

Jorgensen (1982) measured the coefficients of thermal expansion and contraction of several addition cured silicones. Dies were made from impressions from various different temperature changes and time periods. The results showed that a reheating of the impressions to mouth temperature before pouring dies, reduced their inaccuracies significantly.

Carlyle (1983) selected twelve irreversible hydrocolloid impression materials and tested their compatibility with three representative dental stones.
This study showed that when selecting irreversible hydrocolloids factors such as smoothness of cast surface, texture, resistance to abrasion, stone surface hardness, cost and ease of handling, are more important in clinical use than groove reproduction alone.

If an impression material has a low tear energy then there is more likely to be a tear in the gingival region of an impression. Cook et al (1984) investigated the curing time dependance of the tear energy, tensile strength and ultimate extension ratio of different impression materials. Using applied mathematic principles they found that both the tear energy and the ultimate extension to break were found to increase in the following order, agar hydrocolloides/alginate/condensation silicones/addition cured silicones/polyethers/polysulfides. The data indicates that there may be an optimum clinical time for removal of the impression from the mouth; however, a compromise may be required between this time and the time at which the permanent set attains, clinically accepted values.

Doukoudekis et al (1984) investigated a new irreversible hydrocolloid which was claimed by the manufacturers as having excellent accuracy properties which make it possible to fabricate cast crowns and bridges. It was also claimed that pouring of models from this material could be delayed for 36 hours without any considerable loss in accuracy. After comparing this
material with a polyether and a silicone, it was found that this material is accurate enough for use for impressions of single crowns or inlays only, provided however that models are poured immediately. When the pouring of casts were delayed or when more than a single preparation was impressed, the results were not as good as when polyethers and silicones were used.

Hollinger et al (1984) carried out an investigation to determine which tray modification was instrumental in pouring the most accurate irreversible hydrocolloid impressions. The study included a clinical as well as a laboratory part and the results showed that clinically the tray-compound-adhesive combination produced casts that were, on the average, more accurate than the tray compound or tray alone casts.

Stewart et al (1984) evaluated the performance of reversible hydrocolloid impression material in a wet field. Due to its hydrophillic properties, the reversible hydrocolloids theoretically have the capability to duplicate a moist surface either by displacing or absorbing the moisture present, thereby producing an accurate impression. The conclusion was that reversible hydrocolloids used in a wet field produced dies as accurate as those produced in a dry field. There was no difference in the surface quality of the dies produced from both situations.
CHAPTER THREE

THE REVERSIBLE/IRREVERSIBLE HYDROCOLLOID COMBINATION IMPRESSION TECHNIQUE

The earliest reference to this technique was made by Schwartz way back in 1951 when he wrote "Alginate material does not lend itself to use in a syringe to be ejected through a fine needle but hydrocolloid does. Why not try using both at the same time? Even though hydrocolloid is heated to a liquified state for ejection and alginate is mixed cold to make a paste, experiments proved that they could be used together for the one impression, and that they unite in a homogeneous surface and the impression is sharp and clear in detail".

Further reference to this combination procedure was made by Skinner and Hoblit (1956). Even though little detail is given, it is noteworthy to consider the following comments made by the authors. "In conclusion, the technique involving the use of a reversible impression material for the prepared cavity, with the irreversible impression material in the tray deserves special consideration. The irreversible hydrocolloid material does not unite with the reversible materials it comes into contact. Any union is strictly mechanical. In order to strengthen the mechanical union, Hollenback advocates that the reversible hydrocolloids be injected into the prepared cavity in excess, and then
a small specially formed piece of perforated metal is laid over the hydrocolloid. When the irreversible hydrocolloid is brought into contact, the reversible material is cooled and gelled and the perforations in the metal unite the two materials firmly together mechanically". The authors reported that the accuracy of impressions taken by this method was comparable with other techniques.

This technique is not reported in the literature during the three decades which followed, and in 1980 an altered reversible hydrocolloid (Dentaloid) was commercially made available which claimed to bond with irreversible hydrocolloids (alginates).

Appleby et al (1980) were the first to report the use of this new material by investigating the dimensional stability and the strength of the bond. They used the materials to make impressions of a specially fabricated brass master model. The impressions were poured in dental stone and the dimensions of the test samples were compared to those of the original model. Three different irreversible hydrocolloids and three different reversible hydrocolloids were tested in all nine possible combinations. The authors found that the combined impressions of Dentaloid with two of the three tested irreversible hydrocolloids exhibited dimensional stability that was clinically accepted. This combination technique in itself proved to be easy and practical and overcame
many of the shortcomings inherent in conventional reversible hydrocolloids. Nevertheless the three irreversible hydrocolloids exhibited different bond strengths with the Dentaloid. The Dentaloid/irreversible hydrocolloid with the lowest bond strength exhibited the lowest dimensional stability. The usefulness of this material in clinical application is well demonstrated in a follow up article by Appleby et al (1981) where they describe techniques in the construction of partial veneer restorations, cast post and cores and fabrication of a porcelain fused to metal restoration for an existing removable partial denture.

A yet another clinical application of this technique is reported by Fusayama et al (1982) where they used an altered reversible hydrocolloid (Dentroid) which adhered to a modified irreversible hydrocolloid (Vericol Aroma). Vericol Aroma is claimed to be adhesive to most of the reversible hydrocolloids which are commonly in use. The dimensional accuracy of stone casts poured from this combination technique as well as casts produced from four other conventional materials were compared by an outer and inner comparative measuring apparatus. There was no marked difference between these five materials. In a fine line reproducability test it was shown that the surface accuracy was equivalent to polysulfide and silicone rubbers. It was concluded that the laminated hydrocolloid indirect impression technique was simple,
accurate and eliminated the disadvantages of both materials when used individually.

Appleby (1983) described the use of a reversible hydrocolloid preparation (Colloid 80), which bonded with Jeltrate alginate. The alginate was mixed with 10% more water than usual according to the manufacturer's instructions for this combined procedure. The working temperature of Colloid 80 is less than that for conventional reversible hydrocolloid, so that there would be less thermal injury to the pulp. This material sets faster than most other elastomers and therefore this should be an advantageous factor when used in patients who tend to gag. As pointed out by the author, this system does not require the use of water cooled trays, tempering bath and the associated plumbing.

All these aforementioned studies have concentrated mainly on the practical aspects of the use of this combination technique and its applications clinically. An investigation was carried out to compare the dimensional accuracy of the reversible/irreversible system with other commonly used elastic impression materials - polysulfides, silicones, polyethers, reversible hydrocolloids and the irreversible hydrocolloids. A metal duplicate of a maxillary dentulous cast was used as the master model. Stone casts poured from impressions from these materials were measured and the results were statistically analysed.
There was no statistically significant difference between the measurements of the various materials tested and those of the master model. The authors concluded that the dimensional accuracies of all the materials tested were similar (Herring et al. 1984).

In a study recently published, Dahl et al. (1985) investigated the bond strength and the dimensional stability of five different combined reversible/irreversible hydrocolloid impression materials. The dimensional stability was tested after the impressions were kept in a humidor for 1, 3 and 24 hours before casts were poured. Findings showed that there was a true bond between the syringe and the tray materials for all combinations. The authors concluded that from a clinical point of view, all the materials could be used for fixed prosthodontic impressions even if kept for 1 and 3 hours in 100% humidity before pouring the casts.
CHAPTER FOUR

METHODS UTILIZED TO DETERMINE ACCURACY

One of the outstanding early contributions from a practical standpoint in investigating the accuracy of impression materials was reported by James (1949). He made three preparations on porcelain tube teeth: a) mesio-occlusal cavity, b) a three-quarter crown, and c) mesio-occluso-distal cavity with a disto-lingual veneer. Impressions were taken of these preparations; models cast and cast gold restorations were constructed. The fit of these castings was the criterion for accuracy of the models obtained from the impressions. However, no quantitative measurements were made in this study. Similar studies were conducted by Phillips and Ito (1951), Phillips et al. (1953).

Skinner and Hoblit (1956) constructed two oversized abutment molar teeth on a marble base and typical MOD cavities were prepared in the two teeth. Platinum markers were fused into the four gingival and two occlusal bases of the prepared cavities and reference marks were inscribed on the markers. The distances between the markers were measured. Three reversible and two irreversible materials were used to take impressions of this model and after removal the distances between the impressions of the gauge marks were carefully measured under a measuring microscope.

Ayers et al. (1960) used stainless steel cylinders with
three scales of seven indentations. Different impression materials were used to secure impressions of the three test models. The authors pointed out that the duplication of surface detail is dependant on both the interfacial relationship between the impression material and the original object and the compatibility of the impression material and the cast material. After an impression was made, it was observed for the number of indentations reproduced in the impression material. Then after pouring the models again the number of indentations on the models were recorded. The per cent duplication of the total number of indentations possible were calculated to compare the different impression materials.

Podshadley et al (1970) designed a model to determine the accuracy of stone casts reproduced from impression materials. The stainless steel master die was constructed in such a way that it permitted numerous comparative measurements of both horizontal as well as vertical dimensions accurate to 0.0001 inch. This master die simulated two intra-extra coronal cavity preparations. Impressions were made and stone casts poured from these. Vertical and horizontal measurements were made with the help of a dial indicator and a micrometer caliper respectively and the deviation from the master die for each measurement were then calculated.

Stackhouse (1970) used 5 stainless steel master dies which were embedded in a clear resin block. These
master dies had micromarks which provided critical reference points for subsequent measurements. After impressioning, stone casts were poured and the individual metal master dies and all of the gypsum replicas were measured (length and diameter) at 100 x to ± 0.0003" on a measuring microscope. The results were subjected to a statistical analysis. The author assumed that the maximum 0.01% expansion of the die stone was well below the measuring capability of the test system. As such the observed variations in the lengths and diameters of the dies were believed to be caused almost entirely by the impression materials.

Brown (1973) carried out an investigation by taking impressions of a lubricated, highly polished non-undercut metal master model. The impressions were poured in stone and the linear expansion of this stone was determined from ten measurements using a mikrokator to be +0.13%. A micrometer was used to obtain the diameter of 10 positions around the circumference of the models.

Sawyer et al conducted three studies (1973, 1974 and 1976) and in all these studies they utilized the same test model described by Podshedly and co-workers (1970).

Stackhouse (1975) in his study used three extracted teeth. Preparations were made to approximate a partial veneer crown, a full crown and a MOD preparation. These preparations were designed to facilitate laboratory
measurements rather than to represent preparations used in clinical practice. The teeth were mounted in a low fusing metal block and fastened with wires passing through holes in their roots. The metal block also had two stainless steel dies so that it was possible to measure the diameters of their stone replicas. Master castings of a type III gold alloy were made for the three natural tooth preparations. The test castings in this study were made to provide maximum visibility between the edge of the castings and the margins of the preparations. Scribe marks were made with a scalpel at one point on the two crowns and at two points on the inlay. The distance between these four measuring points and the margins of the preparation revealed how far the castings would be seated. The stone die replicas were measured by an identical technique using the same master castings.

Stauffer et al (1976) used a metal master model with four abutment teeth for which a metal master partial denture was constructed. Stone casts were poured from different impression materials and the metal master denture was tried on and the fit was assessed visually and the displacement of the teeth were measured. The authors used one abutment as the point of origin and the measured displacements of the other three abutments were interpreted as displacement vectors. Deformation of the reproduction was defined as the surface area generated by rotation of the vector from the reference
direction. Therefore, the inaccuracy was represented as a surface deformation.

Luebke et al (1976) compared the effect of delayed and second pours on elastomeric impression material accuracy. For their study they utilized a brass master die with four posts arranged in a square. All sides of the posts formed a 90 degree angle to the horizontal plane of the base. Impressions were taken of this master die from various impression materials and models poured. The measurements of the distance between the posts on the metal master die and on the stone replicas were recorded by an optical measuring microscope which was capable of measuring to the nearest 0.0001 inch.

Appleby (1980) also used a brass model which consisted of four abutments milled parallel at all surfaces to be measured thus providing 10 standard measurements. A micrometer caliper and depth gauge which were accurate to 0.001 inch, were used for the measurement of stone dies.

A maxillary dentulous cast that contained fifteen natural teeth was used by Herring et al (1984) for their study. For an impression of this cast, Mallott's metal was melted and poured into the impression whereby teeth with a metal coating was obtained in the master model. On it six fiducial marks were placed on:
a) one point on the mesio lingual cusp tip of each of the second molars;
b) one point on the lingual cusp tip of each of the second premolars;
c) one point in the deepest portion of the palate;
d) one point on the mesio incisal edge of the right central incisor.

Measurements were made with a Unitron UFM measuring microscope accurate to 0.0001 inch. The reference points were such that it was possible to obtain three dimensional distances.

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CHAPTER FIVE
FIT OF CROWNS

Any review on fit of crowns will not be complete if reference is not made to Jorgensen's (1960) landmark article on film thickness of zinc phosphate cements. He used specially prepared plastic crown preparations and precision machined test crowns. The difference in fit of the metal crown before and after cementation was taken as a measure of cement film thickness. Various factors which influence the film thickness is discussed in depth by Jorgensen in his paper.

A well controlled study for testing the marginal fit of gold inlay castings is reported by Christensen (1966). Ten dentists were requested to evaluate the marginal adaptation of inlays using an explorer. The marginal opening for each section was measured microscopically. In accordance with his results, Christensen concluded that a gingival margin discrepancy of 74 µm and an occlusal margin discrepancy of 39 µm were clinically acceptable values for fit of castings.

Grieve (1969) used a similar method and found that the film thickness for cement varied between 84 µm and 90 µm for both polycarboxylate and zinc phosphate cements.

Jones et al (1971) constructed crowns and vents were placed in the occlusal surfaces. The marginal adaptation was measured with an intra-oral television
microscope measurement method.

In a different technique Silness (1973) made use of formulated mathematical equations to calculate the total area of discrepancy at the gingival margin.

The method by Dimashkieh et al (1974) involved replication of cone shaped preparations to produce crowns by electro deposition of copper. The crowns were then cemented into position and after setting was sectioned vertically and the film thickness was measured. However, it should be noted that due to the very close fit of the crowns, it can be anticipated that there would have been a lack of room for the cement. This differs from the actual clinical situation where invariably there would be some inherent distortion during the fabrication of the crowns which would allow some room for the cement.

Strating and associates (1981) evaluated the fit of ceramo-metal restorations. Sixty ceramo-metal crowns and metal copings were constructed on sixty master stone dies and cemented with Durelon. All samples were sectioned sagitally with a low speed saw and a stereo grid microscope was used to measure the width of the cement line at six different locations on each sample.

More recently, Plekavich and Joncas (1983) studied the adaptation of gold crown margins prepared from three impression-die combinations. After cementing the crowns to prepared human teeth, they were embedded
in a hard resin, sectioned and the degree of marginal opening was measured by means of a linear ocular micrometer. Even though it is mentioned that four areas on each tooth was measured, the exact reference points are not detailed. It was found that crowns prepared on silver dies from polysulfide impressions had a smaller margin opening than crowns made on dies of improved stone from silicone and polyether impressions.

The method used by Stewart et al (1984) was to compare the fit of a gold casting (made on a full crown preparation of an extracted lower first molar) on the stone dies poured from impressions. The size of the marginal gap between the margin of the casting and in each stone die was measured at six locations with a comparator microscope accurate to 5 μm.

An entirely new technique was reported by McLean and von Fraunhofer (1971) to estimate the cement film thickness under cast crowns.

Instead of using cement, these investigators devised a technique employing a polyether rubber impression material to 'cement' the crowns. Thereafter this thin film of impression rubber was embedded in an epimine resin, and these specimens were sectioned to measure the film thickness at various points. Polysulfides and silicones were found to be not suitable for this purpose because they did not combine with the epimine
resin. McLean and von Fraunhofer reported that the polyether material had similar working time, setting time and flow characteristics to zinc phosphate cement. Also the shrinkage of the epimine resin was very low and was sufficiently elastic to permit withdrawal of the rubber intact from the tooth or crown surfaces.

McLean claimed by this method, films as thin as 10 μm could be reproduced and there were several other advantageous factors - the technique was simple to carry out, could be used in in-vivo as well as in-vitro conditions and no sophisticated equipment was necessary.

This technique involving the taking of a rubber replica of the gap between the tooth preparation and the restoration and then determining the thickness of the rubber was adapted for an in-vitro investigation by Walton (1978) to measure the axial discrepancies of cemented anterior full veneer restorations in the shoulder area. Three types of anterior crowns were compared: porcelain jackets fabricated by a platinum foil technique, porcelain jackets fabricated by a refractory die technique and porcelain fused to metal crowns. The crowns were assessed for their clinical acceptability and only crowns with average axial discrepancies exceeding 80 μm were considered unacceptable for clinical use.
SUMMARY

In the early days, materials such as wax and compound were used to record impressions of tooth preparations. However, it was practically impossible to take an impression with complete accuracy and the restorations fabricated on stone models poured from them were far from satisfactory.

The introduction of the agar hydrocolloid in the 1920s was the first major breakthrough in dental impression materials. Apart from having sufficient elastic memory to undergo momentary distortion with complete return to dimension, it also had a high degree of accuracy.

In the years that followed, irreversible hydrocolloid, polysulfides and condensation cured silicones were made available. Subsequently polyethers and more recently addition cured silicones were introduced. The newest addition to this array of elastic impression materials is the combined irreversible/reversible hydrocolloid technique.

This review has attempted to discuss the general physical properties of all these classes of elastic impression in brief. The major part has reviewed all the important studies carried out to test the accuracy of these materials. Special reference and emphasis has been made to the comparative accuracy studies. The final part of the review has included a section on studies and various methods carried out to examine the fit of crowns on teeth and stone dies.
PART B

ORIGINAL INVESTIGATION
PART B

ORIGINAL INVESTIGATION

Statement of the problem
The aim of the investigation

Various methods have been used to measure the accuracy and elastic limit of dental impression materials. In general, tests to determine the accuracy can be categorized into one of the following:

1. Linear tests: With this method, the linear dimensional changes are measured in the material itself (Fairhurst et al. 1956, Jorgensen 1957, Miller et al. 1960).


3. Accuracy tests employing the use of master dies and castings (Stackhouse 1976).

The AIM of the present investigation was:

To compare the accuracy of a combined reversible/irreversible hydrocolloid impression material with a conventional hydrocolloid, a polysulfide and addition cured silicone impression materials.

The problem of accuracy in a complete arch impression is two-fold:

a) general accuracy which is the positional relation of the different dies within the dental arch;

b) local accuracy of each die.

In carrying out the present investigation, consideration was given to both these factors.
Establishing the method

The present investigation was carried out in two parts encompassing both general accuracy and local accuracy explained earlier, and are not inter-related.

Investigation A concerns the general accuracy of four classes of dental impression materials. A chrome plated brass model representing a dental arch was utilized for the purpose. Dimensions of stone dies poured from impressions taken of this model was measured and compared.

Investigation B relates to the accuracy of the fit of a master casting on stone dies. For this purpose a chrome cobalt die simulating a jacket crown preparation was inserted on to a plastic Columbia Dentoform*. Impressions were taken of this model from the four classes of impression materials mentioned earlier.

These studies will now be detailed.

* Columbia Dentoform Corp., New York, U.S.A.
INVESTIGATION A

Investigation A was carried out to determine the general accuracy of impression materials. A chrome cobalt master model was used for this purpose.

Materials

There are a vast number of impression materials available and marketed by different dental manufacturing companies. It is impractical to test all or most of these different brands in a study of this nature, and therefore it was decided to test one material from each of the different classes. Due to the obvious superiority of addition cured silicones over the condensation type, it was decided not to include an example from the latter material. Polyether material had to be omitted because it had to be utilized in a different context in the investigation B.

During a pilot study it was revealed that models poured from the addition cured silicone, Reprosil*, had a large number of surface porosities (fig. 5). Models were poured after 15, 30, 45 minutes and 1 hour after removal and even though the surface porosity became progressively lessened, it was not at all suitable for an accuracy study of this nature. Models poured even after three hours contained an unsatisfactory surface. President** impression material therefore was used as the silicone.

* De Trey AG, AD International, London.
** Cotlene Inc., Zurich, Switzerland.
<table>
<thead>
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<th>Material</th>
<th>Consistency</th>
<th>Trade Name</th>
<th>Batch No.</th>
<th>Manufacturer</th>
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<td>4080 104</td>
<td>Dent Products, Japan</td>
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<tr>
<td>combination</td>
<td>(irreversible)</td>
<td>Jeltrate</td>
<td>030784 3</td>
<td>L.D. Caulk Co., USA</td>
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<td>Permlastic</td>
<td>031284 1026</td>
<td>Kerr Mfg. Co., USA</td>
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<tr>
<td></td>
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<td>Permlastic</td>
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</tr>
<tr>
<td>Addition cured</td>
<td>heavy bodied</td>
<td>President</td>
<td>120983 64</td>
<td>Cotlene AG, Switzerland</td>
</tr>
<tr>
<td>silicone</td>
<td>light bodied</td>
<td>President</td>
<td>050983 59</td>
<td>Cotlene AG, Switzerland</td>
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<tr>
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<td>29970</td>
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<tr>
<td>hydrocolloid</td>
<td>(syringe material)</td>
<td>Super syringe</td>
<td>022384 2</td>
<td>Gingi-pak Labs, USA</td>
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</tbody>
</table>
For the combination technique, Colloid 80* was the modified reversible hydrocolloid used in conjunction with the irreversible hydrocolloid Verical Aroma**. It was found that there appeared to be an inferior bonding between these two materials and during removal of the impression the reversible hydrocolloid tended to detach in parts from the alginate. When Colloid 80 was tried out with Jeltrate*** it was noticed that there was a far better bonding between the two materials. The impression materials tested are shown in Table 1.

**Apparatus**
The master model utilized for the investigation is shown in fig. 1. This consisted of a heavy, chrome plated rectangular brass base plate with the dimensions 100 mm x 80 mm x 25 mm. To simulate an alveolar ridge a horse shoe shaped part made from the same material was mounted on the base and three stainless steel posts projected from this ridge. These posts had a minimal taper of 2° which helped to reduce the drag when impressions were removed. On each of the three posts there were parallel facets which enabled measurements AB, BC and AC to be carried out by a micrometer caliper (fig 4). Positioning of the caliper was facilitated by the presence of small shoulders on each measuring facet, at equal heights above the ridge. The design of this

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* Dent Products Co. Ltd., Tokyo, Japan.
** GC Dental Industrial Corp., Tokyo, Japan.
*** LD Caulk Co., Delaware, U.S.A.
Figure 1: Illustration of master model
model was such that it allowed measurement of medium spans (AB and BC) and a long span across the heels of the model (CA).

**Impression trays**

Custom made trays were used for both polysulfide and addition cured silicone impression materials. The general consensus is to have a 2 mm thickness of impression material between the tray and the teeth. Accordingly two sheets of modelling wax* was adapted to cover the ridge and the posts and custom trays were prepared with Tray Resin**. Three metal pins were incorporated in the resin in line with the three holes on the model. This was to facilitate the positioning of the tray during impression taking. (fig. 2).

For the reversible hydrocolloid material, water cooled trays*** and for the combination system, perforated alginate trays**** were used.

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* Investo Mfg. Co., N.S.W., Australia.
** L.D. Caulk Co., Delaware, U.S.A.
*** Van R Dental Products Inc., Los Angeles, U.S.A.
METHOD

Experiment A : 1  The combined reversible/irreversible hydrocolloid impression system

According to the manufacturer's recommendations Colloid 80 cartridges were boiled for 10 minutes and then placed in a storage bath of water with a temperature of 63°C for a minimum of 10 minutes.

Perforated alginate trays (size A-3) were utilized to record the impression. In order to retard the setting time of alginate, 3 parts of Jeltrate* alginate powder was mixed with 4 parts of 10°C cool water. The mix was loaded on to the tray and kept aside.

A Colloid 80 cartridge was taken out of the storage bath, loaded in the special syringe (fig.2a) and the material quickly syringed around and over the three posts. Immediately following this, the loaded alginate tray was seated on the model.

When the alginate was set the impression was removed and stone was poured immediately.

Five such models were poured from five separate impressions.

Experiment A : 2  Polysulfide impression material

Custom trays were coated with a layer of Kerr adhesive**

* L.D. Caulk Co., Delaware, U.S.A.
** Kerr Mfg. Co., Michigan, U.S.A.
and allowed to dry for ten minutes.

To simulate clinical situations, Permlastic\textsuperscript{*} light bodied material was mixed according to the manufacturer's recommendations and injected around the three posts of the master model. Immediately the custom tray loaded with Permlastic heavy bodied material was seated aided by the guide pins and pressed firmly so that the rim of the tray came in close contact with the base of the master model.

Five additional minutes to the manufacturer's recommended setting time was added before the tray was separated with a snap from the master model. Models were poured within 5 minutes of taking the impression.

In all, five different impressions were made.

\textbf{Experiment A : 3} Addition cured silicone impression material

Custom trays were coated with a silicone adhesive\textsuperscript{**}. President\textsuperscript{***} light bodied and heavy bodied impression material was used and the technique was the same as in experiment A:2. A time period of one hour was allowed to lapse before pouring the models, as recommended by the manufacturer. Five such impressions were taken of the master model.

\textsuperscript{*} Kerr Mfg. Co., Michigan, U.S.A.

\textsuperscript{**} Cotlene AG, Switzerland.

\textsuperscript{***} Cotlene AG, Switzerland.
Experiment A : 4  Conventional reversible hydrocolloid

A water coolant tray was used. The syringe material (Super Syringe\*\) and the tray material (Rubberloid\**) was boiled for ten minutes and placed in the storage bath of water with a temperature of 63°C for a minimum of 10 minutes. The tray material was loaded on to the tray and left in the tempering bath for another 10 minutes. The syringe material was injected around the three posts, the loaded tray seated over it and water was allowed to pass through the tray for 5 minutes. Immediately upon removal of the tray, stone was poured.

Stone dies

All dies were poured with Velmix\*** stone which had a one hour setting expansion of 0.05%. In order to have a uniform mix, pre-weighed 50 gram packets were used (fig.2b). The Velmix powder was hand spatulated with the recommended water ratio of 12 cc, for 45 seconds and vibrated into the impressions.

Models poured from polysulfide, addition cured silicones and agar hydrocolloids were removed one hour after pouring. However, during the pilot study it was found that when models from Colloid 80 impressions were left for one hour, the material was found to adhere in parts to the stone surface. This effect was minimized when the models were removed 15 minutes after pouring (fig. 7).

\* Gingi-pak Labs, Belpoint Co. Inc., California, U.S.A.
\** Van R Dental Products Inc., Los Angeles, U.S.A.
\*** Kerr Mfg. Co., Delaware, U.S.A.
Measurement of stone dies:

The AB and AC distances were measured with a 2" - 3" micrometre caliper* and the shorter distance of BC was measured by a 1" - 2" micrometre caliper* (fig. 4). On each model three measurements were made of each of the three distances, AB, BC and AC. These measurements were converted to centimetres with the help of a pocket calculator.**

* Moore & Wright, Sheffield, England.
** Casio Computer Co. Ltd., Tokyo, Japan.
INVESTIGATION B

The objectives of Investigation B were:

a) To determine the internal fit of a master cast gold crown to stone dies poured from impressions of a chrome cobalt master die by measuring the space using a rubber replica technique.

b) To compare and relate this space to the fit of the gold crown to the chrome cobalt master die.

Materials

Four classes of impression materials were investigated, namely:

a combined reversible/irreversible hydrocolloid impression system (Colloid 80*/Jeltrate**);

a polysulfide (Permlastic***);

an addition cured silicone (President****);

a conventional reversible hydrocolloid (Van R Rubberloid*****).

Master die

A chrome cobalt die simulating a jacket crown preparation of a maxillary left central incisor was constructed. It was lathe turned to ensure the absence of undercuts and was highly polished. Two layers of 0.05 mm thick lead

* Dent Products Co. Ltd., Tokyo, Japan.
** L.D. Caulk Co., Delaware, U.S.A.
**** Cotlene AG, Switzerland.
***** Van R Dental Products Inc., Los Angeles, U.S.A.
foil were closely adapted around the die and swaged. The edge of the lead foil was not trimmed. The die was then placed in its correct position on a Dentoform* model and a mix of Duralay** was flowed around it up to the edge of the outer rim of the shoulder. Thus the chrome cobalt die was fixed firmly in position. Adjacent to the labial and palatal shoulders of the die, the Duralay was trimmed so that two rectangular locating depressions with sharp line angles were formed (figs. 8, 9, 10).

Master crown

While the two layers of lead foil remained in place on the die, a wax pattern for a crown was made. This wax pattern had two extra parts labially and palatally which fitted snugly to the two locating depressions described above. The lead foil spacer was necessary for two reasons:

1) there was provision for a measurable space between the gold crown and the chrome cobalt die;

2) both positive and negative variations of the space between crown and the die were able to be determined.

The external contour of the crown was not completed to correct anatomical form as the external shape was immaterial. The thickness of wax used for this wax pattern was 3 mm. The wax pattern was invested with

* Columbia Dentoform Corp., New York, U.S.A.
** Reliance Dental Mfg. Co., Illinois, U.S.A.
Crystabalite* investment material and after the burn out procedure the crown was cast in type B Gold**. The button was left intact to the crown in order to facilitate removal of the crown during later stages of the experimental procedure (fig.11).

At this stage, the two lead foils were trimmed off from the chrome cobalt die.

Thus a master crown was made which could be located in the same positional relation to the chrome cobalt die. The experimental procedure to measure the existing space between crown and die will now be detailed. The remainder of the experiments in relation to the accuracy of the impression materials are based on this space.

** Engelhard Industries Pty. Ltd., N.S.W., Australia.
Procedure to obtain a rubber replica of the space between the outer surface of the chrome cobalt die and the internal surface of the gold casting.

Equal lengths of base paste and the catalyst paste of Impregum* polyether impression material were mixed according to manufacturer's instructions. A small amount of this material was applied to the inner surface of the master crown and the crown was seated on the die with maximum digital pressure. Once the Impregum was set the crown was pulled off with a snap and the Impregum 'impression' remained bound to the crown. This rubber replica thus represented the space between crown and die.

One turn of Scutan** paste and a drop of accelerator was mixed and poured into the inside of the crown with the Impregum space replica. Because of their chemical compatibility the Scutan firmly adhered on to the Impregum replica and they came out in one piece when separated from the crown (fig.17).

This Scutan 'die' with the rubber covering on its outer surface was placed inside a box (15mm x 15mm x 15mm) made out of red modelling wax***, so that its midline in a labio-palatal plane corresponded to a line marked on the walls of the wax block (fig.19).

* ESPE, Oberbay, West Germany.
** ESPE, Oberbay, West Germany.
*** Investo Mfg. Co., N.S.W., Australia.
A second mix of Scutan was poured to cover the entire surface of the rubber replica and 'die'. In this manner a block of Scutan with the embedded rubber replica of the space between crown and die was obtained. Five such rubber replicas were made from the chrome cobalt die and the master crown and a mean calculated from the measurements. The procedure of measurements will be described later on in this chapter. This was the "original" space and all measurements were related to this.
Experiment B : 1 Combined reversible/irreversible hydrocolloid impression system

According to the manufacturer's recommendations Colloid 80 cartridges were boiled for 10 minutes and then placed in a water storage bath with a temperature of 63°C for a minimum of 10 minutes.

Perforated alginate trays* (size A-3) were utilized to record the impression. In order to retard the setting time of alginate, 3 parts of Jeltrate alginate powder were mixed with 4 parts of 10°C cool water. The mix was loaded on to the tray and kept aside.

Colloid 80 cartridge was taken out of the storage bath, loaded in the special syringe and the material was quickly syringed around the chrome cobalt die. Immediately following this, the loaded alginate tray was seated on the dentoform model.

When the alginate was set, the impression was removed and stone was poured immediately. All dies were poured with Velmix** stone. In order to have a uniform mix, pre-weighed 50 gram packets were used. The powder was spatulated with the recommended water ratio of 12cc for 45 seconds and vibrated into the impression.

Five such models were obtained with five separate impressions.

** Kerr Mfg. Co., Michigan, U.S.A.
Twenty four hours after pouring the models, the following procedure was carried out to obtain a rubber replica of the space between the stone die and the master gold crown.

Equal lengths of base paste and catalyst paste of Impregum polyether impression material were mixed. This mix was applied to the inside of the master gold crown and the crown was seated on the stone die with maximum digital pressure. Once the Impregum was set the crown was pulled off. The Impregum replica of the space between the crown and the die remained on the stone surface.

One turn of Scutan and a drop of accelerator was mixed and poured over the die. Once the Scutan was set, the rubber replica bonded to the Scutan was pulled out from the die with the help of a large pair of tweezers. Upon removal another mix of Scutan was allowed to flow inside the rubber replica. The rubber replica embedded in Scutan was now placed in a box (15mm x 15mm x 15mm) made out of red modelling wax. Another mix of Scutan was poured up to the edges of the wax box. Thus a Scutan block with the embedded rubber replica was obtained.

Five Scutan Blocks from the five stone models were made.
Experiment B : 2  Polysulfide impression material

Custom made trays made with Tray Resin* were used. Permlastic light-bodied material was mixed according to the manufacturer's recommendations and the material was syringed around the chrome cobalt die. Immediately, the custom tray loaded with the Permlastic heavy-bodied material was seated over the plastic teeth in the dentoform model.

Once the material was set the impression was removed and a model was poured with Velmix stone.

Four further impressions were taken and in total five stone models were obtained.

From these five stone models, five separate Impregum rubber replicas were obtained by using the master gold crown, in the same manner described in experiment B:1. These Impregum rubber replicas were embedded in Scutan blocks.

Experiment B : 3  Addition cured silicone impression material

Five impressions of the chrome cobalt die were taken using addition cured silicone (President) material on custom made trays. Models were poured one hour after removal, according to manufacturer's recommendations.

The same procedure described above, of obtaining rubber replicas from the five stone dies was carried out.

* L.D. Caulk Co., Delaware, U.S.A.
Experiment B : 4  Reversible hydrocolloid impression material

A water cooled tray* was used to take impressions. The syringe material (Gingipak**) and the tray material (Rubberloid*** ) were boiled for 10 minutes and placed in the storage bath with a temperature of 63°C for a minimum of 10 minutes. The tray material was loaded on to the tray and left in the tempering bath for another 10 minutes. The syringe material was injected around the chromecobalt die, the tray seated over the dentoform model and water was allowed to pass through the tray for 5 minutes. The tray was gently lifted off and stone was poured without delay.

Four more impressions were carried out and altogether five stone models were obtained.

In the manner described above, 5 Impregum rubber replicas embedded in 5 Scutan blocks were made.

*  Van R Dental Products Inc., Los Angeles, U.S.A.
**  Gingi-pak Labs, Belpont Co. Inc., California, U.S.A.
***  Van R Dental Products Inc., Los Angeles, U.S.A.
Sectioning the Scutan blocks

To section the Scutan blocks, double-ended diamond slim discs* (fig.19) were used in a straight handpiece. The Scuten blocks were sectioned 1mm either side of the line marked on the Scutan blocks (fig.20) cutting in a labio-palatal plane. Thus an approximately 2mm thin section of Scutan block with embedded rubber space replica was obtained. It was found that this produced the clearest object for measuring under the microscope.

All the Scutan blocks were sectioned in this manner and the two surfaces of these sections were smoothed with silicone carbide abrasive paper** of grits 440, 600 and 1200.

* Horico, West Germany.
** 3M Manufacturing Co., Sydney, Australia.
Microscopic Examination

To measure the thickness of the Impregum rubber space replica, a Cambridge Comparator Microscope (travelling microscope) was used (fig.22). Measurements of each of the space replicas were made in five positions along the outline of the crown. The points measured were (fig.1.2):

a) centre of the labial shoulder;
b) centre of the labial axial wall - 5 mm from incisal edge;
c) centre of the incisal edge;
d) centre of the palatal slope, above the cingulum area (3 mm from incisal edge);
e) centre of the palatal shoulder.

Measurements up to one hundredth of a millimetre were able to be measured from this travelling microscope.
Figure 1.2: Points of measurements of the rubber replica
RESULTS
RESULTS

INVESTIGATION A

Table 2 shows the measurements between the three posts of the chrome cobalt master die. A mean was calculated after five measurements on each of the three distances. It can be seen that there is not much difference between AB and BC whereas AC is comparatively greater.

The same distances measured on the stone dies poured from the four classes of impression materials are tabulated in table 3. Three measurements of each of the distances were made on each die.

Table 4 shows the mean values and the standard deviation of the stone dies as compared with the mean values of the chrome cobalt die.

These data were subjected to an analysis of variance with the aid of a computer and the F values obtained are tabulated in table 5. The critical F values at .05 and .01 significance level were taken from the F tables in Fisher and Yates statistical tables.
Table 2: Measurements of the chrome plated brass master model

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<th>Reading 4</th>
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Table 3: Measurements of stone dies poured from different impression materials

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<td></td>
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Table 4: Comparison of mean measurements of stone dies with those of the master model

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<td>0.0031</td>
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<tr>
<td>silicone</td>
<td>BC</td>
<td>4.9187</td>
<td>0.0050</td>
</tr>
<tr>
<td></td>
<td>AC</td>
<td>6.2470</td>
<td>0.0041</td>
</tr>
<tr>
<td>Reversible</td>
<td>AB</td>
<td>5.1615</td>
<td>0.0046</td>
</tr>
<tr>
<td>hydrocolloid</td>
<td>BC</td>
<td>4.9162</td>
<td>0.0021</td>
</tr>
<tr>
<td></td>
<td>AC</td>
<td>6.2441</td>
<td>0.0046</td>
</tr>
<tr>
<td>Colloid 80</td>
<td>AB</td>
<td>5.1679</td>
<td>0.0032</td>
</tr>
<tr>
<td></td>
<td>BC</td>
<td>4.9226</td>
<td>0.0014</td>
</tr>
<tr>
<td></td>
<td>AC</td>
<td>6.2522</td>
<td>0.0023</td>
</tr>
</tbody>
</table>
Table 5: Analysis of variance

<table>
<thead>
<tr>
<th>Area of measurement</th>
<th>F value</th>
<th>Critical F value*</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>AB</td>
<td>7.58906</td>
<td>2.87(.05)</td>
<td>highly significant</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.43(.01)</td>
<td></td>
</tr>
<tr>
<td>BC</td>
<td>11.87229</td>
<td>2.87(.05)</td>
<td>highly significant</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.43(.01)</td>
<td></td>
</tr>
<tr>
<td>AC</td>
<td>19.87616</td>
<td>2.87(.05)</td>
<td>highly significant</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.43(.05)</td>
<td></td>
</tr>
</tbody>
</table>

F*: From Fisher and Yates statistical tables
Table 6: Mean dimensional change from master model

<table>
<thead>
<tr>
<th></th>
<th>AB</th>
<th>BC</th>
<th>AC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MLDC (cm)</td>
<td>%DC</td>
<td>MLDC (cm)</td>
</tr>
<tr>
<td>Reversible hydro-colloid</td>
<td>0.0026</td>
<td>0.05%</td>
<td>0.0012</td>
</tr>
<tr>
<td>Addition cured silicone</td>
<td>0.0032</td>
<td>0.062%</td>
<td>0.0037</td>
</tr>
<tr>
<td>Colloid 80</td>
<td>0.009</td>
<td>0.174%</td>
<td>0.0075</td>
</tr>
<tr>
<td>Polysulfide</td>
<td>0.0111</td>
<td>0.215%</td>
<td>0.0125</td>
</tr>
</tbody>
</table>

MLDC = Mean Linear Dimensional Change
%DC = Per Cent Dimensional change
RESULTS

INVESTIGATION B

The results in investigation B concern with the measurements of the space between:

a) the internal surface of the master crown and the outer surface of the chrome cobalt die;
b) the internal surface of the master crown and the outer surface of the stone dies poured from different impression materials.

For ease of comparison both these measurements have been grouped together. As described earlier, five positions along the outline of the rubber replicas were measured. These positions are:

1) centre of the labial shoulder
2) centre of the labial axial wall
3) centre of the incisal edge
4) centre of the palatal concave surface
5) centre of the palatal shoulder

These results are shown in tables 7, 8, 9, 10 and 11 respectively.

All the data was fed into a computer and an Analysis of Variance (ANOVA) test was carried out. A null hypothesis was established by assuming that there is no difference between the means of the values of the specimens obtained by the four classes of impression materials and the specimens obtained from the master die.
As in investigation A, the confidence level was set at $p = 0.05$ (95% confidence level). If the calculated $F$ value was less than the critical $F$ value for the corresponding degrees of freedom, then the null hypothesis was accepted. This meant that statistically there is no significant difference between the mean values obtained in this investigation.

The statistical test, Analysis of Variance (ANOVA), was carried out separately for each of the afore-mentioned positions under study.
Table 7: Measurement of Labial Shoulder of the Rubber Replica

<table>
<thead>
<tr>
<th></th>
<th>Mean* (μm)</th>
<th>Standard deviation</th>
<th>F value</th>
<th>critical F value**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Master Die</td>
<td>71.80</td>
<td>7.85</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P*</td>
<td>94.60</td>
<td>21.83</td>
<td></td>
<td>2.87(.05) not</td>
</tr>
<tr>
<td>S*</td>
<td>105.58</td>
<td>42.88</td>
<td>1.5836</td>
<td>4.43(.01) significant</td>
</tr>
<tr>
<td>C*</td>
<td>124.67</td>
<td>53.52</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H*</td>
<td>109.67</td>
<td>29.57</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Mean = Mean of three measurements of five specimens
P = models poured from polysulfide material
S = models poured from addition cured silicone
C = models poured from Colloid 80/Jeltrate
H = models poured from reversible hydrocolloid

** critical F value: From Fisher & Yates statistical tables.
Table 8: Measurements of Labial Axial Wall of the Rubber Replica

<table>
<thead>
<tr>
<th></th>
<th>Mean* (μm)</th>
<th>Standard deviation</th>
<th>F value</th>
<th>critical F value**</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Master Die</td>
<td>149.00</td>
<td>9.05</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P*</td>
<td>145.99</td>
<td>20.29</td>
<td></td>
<td>2.87(.05)</td>
<td>not</td>
</tr>
<tr>
<td>S*</td>
<td>202.72</td>
<td>16.73</td>
<td>5.0471</td>
<td>4.43(.01)</td>
<td>significant</td>
</tr>
<tr>
<td>C*</td>
<td>184.72</td>
<td>40.76</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H*</td>
<td>200.99</td>
<td>36.49</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Mean = Mean of three measurements of five specimens  
P = models poured from polysulfide material  
S = models poured from addition cured silicone  
C = models poured from Colloid 80/Jeltrate  
H = models poured from reversible hydrocolloid  

** critical F value: From Fisher & Yates statistical tables.
Table 9: Measurements of Incisal Edge of the Rubber Replica

<table>
<thead>
<tr>
<th></th>
<th>Mean* (μm)</th>
<th>Standard deviation</th>
<th>F value</th>
<th>critical P value**</th>
<th>significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Master Die</td>
<td>479.40</td>
<td>24.06</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P*</td>
<td>440.27</td>
<td>63.98</td>
<td></td>
<td>2.87(.05)</td>
<td>not significant</td>
</tr>
<tr>
<td>S*</td>
<td>499.59</td>
<td>14.34</td>
<td>2.2147</td>
<td>4.43(.01)</td>
<td></td>
</tr>
<tr>
<td>C*</td>
<td>525.72</td>
<td>67.78</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H*</td>
<td>496.12</td>
<td>37.64</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Mean = mean of three measurements of five specimens
P = models poured from polysulfide
S = models poured from addition cured silicone
C = models poured from Colloid 80/Jeltrate
H = models poured from reversible hydrocolloid

** critical F value: from Fisher & Yates statistical tables.
Table 10: Measurements of Palatal Concave Surface of the Rubber Replica

<table>
<thead>
<tr>
<th></th>
<th>Mean* (µm)</th>
<th>Standard deviation</th>
<th>F value</th>
<th>critical F value**</th>
<th>significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Master Die</td>
<td>236.25</td>
<td>16.09</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P*</td>
<td>224.47</td>
<td>19.62</td>
<td></td>
<td>2.87(.05)</td>
<td>not significant</td>
</tr>
<tr>
<td>S*</td>
<td>262.92</td>
<td>48.55</td>
<td>1.1926</td>
<td>4.43(.01)</td>
<td></td>
</tr>
<tr>
<td>C*</td>
<td>268.79</td>
<td>33.42</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H*</td>
<td>253.25</td>
<td>54.11</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Mean = mean of three measurements of five specimens
P = models poured from polysulfide material
S = models poured from addition cured silicone
C = models poured from Colloid 80/Jeltrate
H = models poured from reversible hydrocolloid

** critical F value: from Fisher & Yates statistical tables.
Table 11: Measurements of the Palatal Shoulder of the Rubber Replica

<table>
<thead>
<tr>
<th></th>
<th>Mean* (µm)</th>
<th>Standard deviation</th>
<th>F value</th>
<th>critical F value**</th>
<th>significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Master Die</td>
<td>293.60</td>
<td>11.15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P*</td>
<td>338.80</td>
<td>57.63</td>
<td></td>
<td>2.87(.05)</td>
<td>not significant</td>
</tr>
<tr>
<td>S*</td>
<td>292.92</td>
<td>58.54</td>
<td>0.9761</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C*</td>
<td>372.00</td>
<td>126.64</td>
<td>4.43(.01)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H*</td>
<td>347.59</td>
<td>90.12</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Mean = mean of three measurements of five specimens
P = models poured from polysulfide
S = models poured from addition cured silicone
C = models poured from Colloid 80/Jeltrate
H = models poured from reversible hydrocolloid

** critical F values: from Fisher & Yates statistical tables.
DISCUSSIONS AND CONCLUSIONS
DISCUSSION

INVESTIGATION A

It will be seen from the results presented in table 3 that the dimensions of the dies poured from all the four classes of impression materials are oversized. This can be due to two reasons. Firstly, the impression materials contract on setting. The direction of this contraction will be towards the wall of the tray due to the material being firmly bound to the tray wall by the adhesive. The relative magnitude of this contraction for the different types of materials has been discussed by Kentwell (1971).

The second reason is the possible effect of the setting expansion of the Velmix stone on the eventual dimensions of the dies. (Velmix has an 0.05% unrestricted setting expansion after one hour).

In the present investigation, the increase in size of the dies is depicted in all the three areas of measurements, whether it is a short span distance as in AB and BC or in a long span distance as in AC. This somewhat differs from the results obtained by Kentwell (1971). In his study in virtually all the dies, the percent dimensional change of AC gave negative values.

During the removal of Colloid 80 and reversible hydrocolloid impressions, the tray had to be lifted as
vertically as possible due to the exact parallelism of the posts. The slightest deviation from the vertical plane resulted in the hydrocolloid material being damaged. This could have been avoided if the posts of the master model were constructed with a slight degree of taper, as in an actual clinical tooth preparation. This disadvantage was not present when using polysulfide and silicone materials, both of which have higher tear resistance.

It was observed during this experiment that some stone models poured from polysulfide impression material (Permlastic) exhibited raised areas on the stone surface. It gave the appearance as sub-surface air bubbles and this has previously been reported by Schnell and Phillips (1958), Miller et al (1960) and also by Kentwell (1971). Stone models poured from the other three classes of impression materials did not show this effect.

One of the most striking features observed during the investigation was that the Colloid 80 material was found to partially adhere on to the stone surface when the models were removed from the impression. The Colloid 80 material, however, did not totally detach itself from the alginate and this shows that there is in fact a bond between the two materials. Dahl et al (1985) reported that there was a true bond between the syringe and the tray materials used in their study.
For the measurements to be carried out, the Colloid 80 which adhered to the stone surface, had to be carefully removed. Even though the material came out comparatively easily, it was observed that a pigment from the Colloid 80 material appeared to stain the stone surface. The same observation was reported by Herring et al (1984). Even though such an effect was not reported in the study by Dahl et al (1985), after removal it was stated that the impressions were placed in a 2% fixing solution prior to pouring the models. However, the authors did not discuss the purpose of such an action.

Yet another problem encountered during the syringing of the Colloid 80 material around the posts of the master die was that it began to set as soon as the material came in contact with the posts. Since these posts were located away from each other in the arch it was almost impossible to syringe the material around all three posts and seat the alginate tray while the Colloid 80 was still in its sol state. This also left no room whatsoever to change cartridges in the syringe when more material was required. When the Colloid 80 material had set prior to seating the alginate tray, there was no bonding between the reversible and the irreversible hydrocolloid materials. Judging from these observations it could be presumed that the reversible/irreversible hydrocolloid impression technique may not be suitable for clinical situations when an impression is needed for widely separated multiple tooth preparations.
However, the brass posts have a high thermal conductivity and this may not be as great a problem on tooth structure at mouth temperature. Manipulation of these impression materials at mouth temperature was not a part of this investigation.

Stone models devoid of air bubbles poured from addition cured silicone material was found to be a hard task. Air bubbles occurred along sharp line angles especially at the circumferential periphery of the three posts. The surface of the impression material was so smooth and shiny that the Velmix stone did not appear to wet the impression surface. This phenomenon described as due to the high contact angle between the silicones and the dental stone was reported by Lorren et al (1976). In actual clinical practice, however, tooth preparations and surrounding gingival tissues are not reproduced with such a high surface lustre as in the experimental model.

As a comparison had to be made between the values obtained from four classes of impression materials and the master model, an Analysis of Variance (ANOVA) was carried out to obtain a statistical significance. As previously mentioned, the confidence level was set at probability $p=.05$ (95% confidence level). A null hypothesis was established at the onset by inferring that there is no significant difference between the four classes of impression materials and the master model. If the calculated F value is more than the
critical F value, the null hypothesis is rejected and it can be assumed that there is a statistically significant difference between the mean values.

At first glance from the data in tables 1 and 2 it seems that all the values obtained in this investigation are very close to each other.

However, from table 4 it is apparent that statistically there is a highly significant difference between the mean values in all the three distances AB, BC and AC. The Analysis of Variance is a highly useful test to obtain a comparison between two or more sets of data. In this instance it has been shown that there is a significant difference between the mean values of stone models obtained from the four classes of impression materials from the mean values of the master model. But this test is not capable of determining whether one material, two, three or all four materials differ from the dimensions of the master model.

In order to determine this factor, another statistical test termed the Least Significant Difference (LSD) was carried out. The LSD analysis on distance AB showed that the stone models poured from polysulfide and Colloid 80 materials differed most from the master model, whereas models poured from the conventional hydrocolloid material and addition cured silicone material were found to be dimensionally very close to the master model and therefore the difference insignificant.
In the distance BC, it was found a similar result; however, the models poured from polysulfide material were found to be the most different from the master model. Models from Colloid 80 were found to have values in between the two groups.

In the longest span AC, once again the same results were obtained; models from reversible hydrocolloid and addition cured silicones being the closest to the master model and models from Colloid 80 and polysulfide being the ones most differing from the master model.

Table 6 shows another interpretation of the data. It shows the mean dimensional change from the master model and the percent dimensional change. Models poured from the reversible hydrocolloid gave the least dimensional change followed by the addition cured silicone, Colloid 80 and finally polysulfide. In the present study, the values obtained for the models poured from the Colloid 80 material are AB-0.163%, BC-0.152% and Ac-0.12%. These figures are lower than the 0.22% obtained by Appleby (1980) using a reversible/irreversible hydrocolloid technique. Skinner et al (1950) suggested that an 0.1% distortion was acceptable for reversible and irreversible hydrocolloid.

The findings reported by Christensen (1966) though directly not applicable to the present study are worth mentioning.
Christensen determined that a proximal gingival margin discrepancy of 74 \( \mu \text{m} \) (microns) was clinically acceptable. Table 6 shows that models poured from reversible hydrocolloids, addition cured silicones and Colloid 80 showed a mean distortion of less than 75 \( \mu \text{m} \) whereas models poured from polysulfide material was found to be very much more than this.

The statistical analysis showed that there is a highly significant difference among the four classes of impression materials and the master model. Yet another method of comparison is to give consideration to the linear dimensional changes. Table 6 shows the linear dimensional changes of the stone dies as compared with the dimensions of the master model. From this table it can be seen that the models poured from the polysulfide impression material have an average linear dimensional change of 0.0111 cm between the posts A and B. If this result is compared to a clinical situation where a fixed prosthesis is constructed to two abutments which are 5.1589 cm apart, this would mean that each abutment will have to move 0.005 cm or 0.05 mm, for the casting to be accurately seated. This amount of tooth movement is negligible.

Similarly, in the same distance AB, models poured from the reversible hydrocolloid material had a linear dimensional change of only 0.0026 cm. If the same principle as before is applied, this would mean that
during the fitting of a fixed prosthesis, each abutment will be displaced only by 0.0013 cm (0.013 mm).

Therefore, even though the statistical analysis appears to show that there is a significant difference between the four classes of impression materials, in an actual clinical situation this difference is so minute that it is not strong enough to influence the accuracy of fit of bridge castings.

Even the measurement across the heel of the model (distance AC) with a relatively long span of 6.2447 cm, the models poured from polysulfide material had a mean linear dimensional change of only 0.0125 cm and models from reversible hydrocolloid a mean linear dimensional change of only 0.0006 cm.

This shows that even though statistically, polysulfides is the material which has the least accuracy, it is still well within clinically acceptable limits.
CONCLUSIONS

Under the conditions of the present investigation, it could be concluded that:

* There was a statistically significant difference between the mean values obtained from dies and the master model in all the three distances investigated for all materials studied.

* Out of all the materials investigated, dimensions closest to the master model were obtained on stone models poured from the conventional reversible hydrocolloid* and addition cured silicone** impression materials in all the three distances AB, BC and AC.

* In the distances AB and AC models from both polysulfide*** and the reversible/irreversible hydrocolloid**** impression materials were found to be farthest away from the master model. In the distance BC, models from Colloid 80 material were found to have values closer to the master model than the models from polysulfides.

* This investigation is most related generally to long span bridges and partial denture cases.

* Van R Rubberloid
** President
*** Permlastic
**** Colloid 80/Jeltrate
DISCUSSION

INVESTIGATION B

It is apparent from tables 7, 8, 9, 10 and 11 that all the calculated F values are in fact less than the critical F values. This means that statistically there is no significant difference between the various measurements in each of the areas of study. In other words, all the four impression materials under study have been able to reproduce the dimensions of the master die with a great deal of accuracy.

The measurements in microns (µm) of the rubber replica should not be confused with the space which exists between dies and crowns which are waxed up and cast. Numerous investigations (McLean and von Fraunhofer 1970, Dimashkieh et al 1974, Walton 1978, Stewart 1984) have been carried out to examine the cement space thickness between crowns and dies but the present investigation cannot be compared with those studies.

In the present study, the thickness of the rubber replica may seem to be far too thick for a cement film, but it is pointed out that prior to the waxing up of the master crown two layers of lead foil were swaged over the chrome cobalt die. Additionally, the internal surface of the cast gold crown was polished to facilitate the removal of the impregum replicas.

As such the present investigation merely compares the
thicknesses of the rubber replicas obtained between
the master crown and stone dies poured from different
classes of impression materials.

The term "good clinical fit of a crown" obviously has
many interpretations. It may vary depending on the
test method utilized, examining clinician and the
sharpness of the instruments. Christensen (1966)
accepted 74 µm as a clinically desirable marginal
discrepancy whereas McLean (1970) points out that gaps
of the order of even 80 µm could be quite difficult
to detect either with an explorer tip or by radiographic
means. Therefore he suggests that if restorations can
be constructed so that marginal gaps and, therefore,
cement films of less than 120 µm are achieved, a
successful restoration is possible. In McLean's study,
using the Impregum rubber replica technique, there was
a high co-efficient of variation of the results ranging
from 45% up to 132% at different points of measurements
in a labio-lingual vertical plane.

Walton (1978) also based his investigation using the
same rubber replica technique. However, his studies
were mainly concentrated on the axial discrepancy in
the shoulder region of porcelain crowns constructed in
different techniques. Among his series of investi-
gations, one study showed that the thickness of the
rubber replica in the shoulder region, axial wall and
the lingual wall was 58 µm, 21 µm and 26 µm respectively
in crowns constructed with a platinum foil and 54 µm, 69 µm and 77 µm on crowns constructed on refractory dies. These results, however, cannot be compared with the results obtained in the present investigation due to the reasons mentioned previously.

The relatively large standard deviation in the results can be attributed to several factors. Firstly, the seating pressure of the master crown would have had a bearing on the thicknesses of the rubber replicas. A method to standardize this pressure would have avoided this variable. Secondly, due to the minute configurations of the rubber replica, it was extremely hard to carry out multiple measurements on an exact area during each measurement. Finally, a more precise measuring instrument than a comparator (travelling microscope) seems more appropriate for an investigation of this nature.

Statistical analysis in this study does not show any difference between any particular class of impression material. However, it would be interesting to analyse these results by comparing the different thicknesses of the rubber replica.

In the region of the labial shoulder, the rubber replicas obtained from stone dies poured from polysulfide impression material had a mean value of 94.60 µm whereas the rubber replica from the master die, had a value of
of 71.80 μm. Rubber replicas from stone dies from addition cured silicones came next with 105.58 μm followed by reversible hydrocolloid 109.67 μm. The rubber replicas which had the most difference were from the Colloid 80 material.

In the labial axial wall measurements, it was interesting to find that the thickness of the rubber replica obtained from models from polysulfides had a less value than the value for the master model - 145.99 μm compared with 149.0 μm. All other values were more than for the master die in the following order: Colloid 80 (184.72 μm), reversible hydrocolloid (200.99 μm) and addition cured silicone (202.72 μm).

Models from polysulfides gave similar results in the incisal edge measurements - rubber replicas being thinner (440.27 μm) than the one from the master model (479.40 μm). Very close values were obtained from the models from reversible hydrocolloid (496.12 μm) and from addition cured silicone (499.59 μm). Rubber replicas from the models from Colloid 80 material differed in this region as much as 46.32 μm from the rubber replicas from the master model.

Similarly, the mean values of rubber replicas obtained from models from polysulfides was less than the rubber replicas from the master die - 224.47 μm and 236.25 μm respectively, in the concave palatal surface. Models from reversible hydrocolloid produced rubber replicas
253.25 μm followed by addition cured silicones 262.92 μm; Colloid 80 once again being the last with 268.79 μm.

The palatal shoulder area gave entirely different results. The difference between the rubber replicas obtained from the master die and from models from addition cured silicones differing by only 0.68 μm - which can hardly be called a difference. However, it was a negative result. In this area, the rubber replicas from polysulfides came next, followed by reversible hydrocolloid and lastly Colloid 80.

Even though these results are somewhat conflicting, it appears that in four of the five positions of measurements (labial shoulder, incisal edge, concave palatal surface and palatal shoulder) models from Colloid 80 were dimensionally most different from the chrome cobalt master model. At the same time, models closest in dimensions to the master model appear to result from polysulfide impression material. The performance of addition cured silicone and reversible hydrocolloid can be positioned in between the polysulfide and Colloid 80 materials.

Whether these results can be interpreted to a clinical situation is arguable. When the rubber replica gets thicker, it means that the stone die is more undersized than the master die. As the stone expands on setting, the only possible explanation for this is the expansion of the impression materials, resulting in
smaller dies. Judging from these results, the polysulfide and the addition cured silicone seem the only two materials which have the capacity to contract on setting and as a result give oversized dies. Nevertheless more research is necessary to find answers to this behaviour of impression materials. The result of undersized dies point out the part which a die spacer material might play during the construction of a crown.

During the course of this investigation, many advantageous facts of the combined reversible/irreversible hydrocolloid system were revealed. Firstly, this system could be used with an alginate tray instead of the water cooled tray and the associated plumbing required for the conventional hydrocolloids. Therefore, this combination technique allows convenience, without having to sacrifice the accuracy obtainable with the reversible hydrocolloid.

The material sets faster than any other elastic impression material because gelation takes place almost immediately once the cool alginate comes in contact with the modified reversible hydrocolloid. Therefore this system could be very useful in patients susceptible to gagging and also for patients having excessive salivation.

With regard to the initial equipment costs, the combination system works out to be very much cheaper than the conventional hydrocolloid system. The cost per impression is also very much less as the bulk of each
impression consists of irreversible hydrocolloid.

Since the Colloid 80 begins to set as soon as it is injected, the timing of mixing the alginate is crucial and therefore a well rehearsed teamwork is vital for successful results.

In the present investigation only one type of modified reversible hydrocolloid was tested with one type of alginate material. However, there seem to be more of these materials being increasingly available in the market. Therefore further research studies involving these new materials seems to be indicated, especially in the area of bond strength between the reversible and irreversible materials and also the adherence of the material to the stone surface.
CONCLUSIONS

* Under the conditions of the present investigation, statistically, there was no significant difference between the rubber replicas obtained from the stone dies poured from the four impression materials studied and from the chrome cobalt die.

* Polysulfide impression material appears to produce stone dies closest to the dimensions of the master die.

* The combined reversible/irreversible hydrocolloid impression technique produced stone dies which differed most from the master die.

* A more precise measuring instrument than a comparator microscope is necessary to measure the thickness of the rubber replica.
The accuracy of a combined reversible/irreversible hydrocolloid impression system was compared with representative samples of polysulfide, addition cured silicone and conventional reversible hydrocolloid impression materials.

The investigation was carried out in two parts. In investigation A, impressions were taken of a chrome cobalt master die of an arch with three posts and stone dies were poured from these impressions. The resultant stone dies were measured and the measurements between the posts were compared with those of the master model. An analysis of variance of the results showed that statistically, there was a significant difference between the measurements. Among the materials studied, reversible hydrocolloid impression material was found to be the most accurate followed by addition cured silicone and the combined reversible/irreversible hydrocolloid impression system. Polysulfide impression material was found to be the least accurate.

In investigation B, a chrome cobalt die simulating a jacket crown preparation and a master gold crown was used. A technique first described by McLean and von Fraunhofer (1971) to obtain an 'Impregum' rubber replica of the space between a tooth preparation and a restoration was utilized to compare stone dies poured from four
different classes of impression materials mentioned above. The thickness of the rubber replicas was measured in five areas and the results were analysed statistically. There was no significant difference between the rubber replicas obtained from the stone models and the chrome cobalt die. However, actual differences were noticed and in order of accuracy were polysulfide, addition cured silicone, reversible hydrocolloid and the combined reversible/irreversible hydrocolloid system.

The clinical relevance of the results has been discussed.
Figure 1: The chrome plated brass master model

Figure 2: (right) A custom made impression tray with the three localizing pins
(left) A typical impression using addition cured silicone impression material (President)
Figure 2a: Colloid 80 syringe with two cartridges

Figure 2b: Pre-weighed Velmix stone packets with measuring jar
Figure 3: Stone models poured from
(left) polysulfide impression material;
(right) reversible hydrocolloid impression
material.

Figure 4: Measurement of stone dies were carried out by a micrometre caliper.
Figure 5: Stone models showing surface porosity when addition cured silicone (Reprosil) was used. (left) poured 15 minutes after taking impression; (right) poured one hour after taking impression.

Figure 6: Close up of above
Figure 7: The Colloid 80 material adhering on to the stone surface
Figure 8: Chrome cobalt die positioned on the dentoform model using Duralay

Figure 9: Side view of the chrome cobalt die
Figure 10: A close up of the chrome cobalt die in position on the dentoform model.
Figure 11: The master gold crown with the attached button after casting
Figure 12: Close up of the master crown positioned on the dentoform model - palatal view (above).

Figure 13: Labial view.
Figure 14: Impregum rubber replica being obtained by positioning the crown over the die
Figure 15: A stone model poured from a Colloid 80/Jeltrate impression of the dentoform model

Figure 16: Master crown positioned on the stone die
Figure 17: (left) Impregum rubber replica of the space between the master crown and the chrome cobalt die

(center) The rubber replica embedded in Scutan within a block made out of modelling wax

(right) The Scutan block after the wax has been removed with the orientation line along the mid axis of the rubber replica in a labio palatal plane
Figure 18: Scutan blocks with embedded rubber replicas

Figure 19: The ultra thin double ended diamond discs (perforated on left and non-perforated on right)
Figure 20: Sectioning a Scutan block (simulated)

Figure 21: Scutan sections with the embedded rubber replicas ready for microscopic examination
Figure 22: The Cambridge comparator microscope
Figure 23: Investigation A - Comparison of linear dimensional change between models poured from different impression materials and the master model. Distance AB.

M = Master model
P = Polysulfide
S = Addition cured silicone
H = Reversible hydrocolloid
C = Colloid 80
Figure 24: Investigation A - Comparison of linear dimensional change between models poured from different impression materials and the master model. Distance BC.

M = Master model
P = Polysulfide
S = Addition cured silicone
H = Reversible hydrocolloid
C = Colloid 80
Figure 25: Investigation A - Comparison of linear dimensional change between models poured from different impression materials and the master model. Distance AC.

M = Master model
P = Polysulfide
S = Addition cured silicone
H = Reversible hydrocolloid
C = Colloid 80
Figure 26: Investigation B - Comparison of rubber replicas obtained from the master die and from stone models poured from different impression materials. LABIAL SHOULDER.

M = Master model
P = Polysulfide
S = Addition cured silicone
C = Colloid 80
H = Reversible hydrocolloid
Figure 27: Investigation B - Comparison of rubber replicas obtained from the master die and from stone models poured from different impression materials. LABIAL AXIAL WALL.

M = Master model
P = Polysulfide
S = Addition cured silicone
C = Colloid 80
H = Reversible hydrocolloid
Figure 28: Investigation B - Comparison of rubber replicas obtained from the master die and from stone models poured from different impression materials. INCISAL EDGE.

M = Master model
P = Polysulfide
S = Addition cured silicone
C = Colloid 80
H = Reversible hydrocolloid
Figure 29: Investigation B - Comparison of rubber replicas obtained from the master die and from stone models poured from different impression materials. CONCAVE PALATAL SURFACE.

M = Master model  
P = Polysulfide  
S = Addition cured silicone  
C = Colloid 80  
H = Reversible hydrocolloid
Figure 30: Investigation B - Comparison of rubber replicas obtained from the master die and from stone models poured from different impression materials. PALATAL SHOULDER.

M = Master model
P = Polysulfide
S = Addition cured silicone
C = Colloid 80
H = Reversible hydrocolloid
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<td>The use of hydrocolloids or alginites as impression materials for indirect or indirect-direct inlay construction procedure.</td>
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