INFLUENCE OF TRAY RIGIDITY AND MATERIAL THICKNESS ON ACCURACY OF POLYVINYL SILOXANE IMPRESSIONS

By

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To my parents and my wife, who are my inspiration

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Abstract of Thesis Presented to the Graduate School
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INFLUENCE OF TRAY RIGIDITY AND MATERIAL THICKNESS ON ACCURACY
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The objective of this study was to determine how tray rigidity and impression technique affect the accuracy of impressions made with an addition polymerizing silicone material. Metallic rim-lock trays and disposable plastic trays were used in combination with three different impression techniques. The three techniques consisted of 1) heavy/light bodied materials in a one-step impression (HL), 2) putty impression without spacer and light body impression made in two steps (PL), 3) putty impression with 2 mm space and light body impression made in two steps (SP). Ten impressions of each combination technique/tray were made of a master model. The master model included two steel abutments (44 and 47) and a steel rod placed at ridge level between the two abutments. Five marks had been placed on each steel abutment. One mark placed on the steel rod in between the two abutments served as a reference point. By use of a universal measuring microscope, the x, y, z-coordinates were recorded for each of the 11 marks on the master model and the impressions. The distances between the different marks and the reference point were calculated and compared with the master model. Using a t-test and pair wise comparisons, significant differences ($p<0.05$) were found between 4 of the investigated groups and the master model. All techniques (PL, SP and HL) used with the plastic trays had distances that were significantly different from the master model, while for the metal trays it was only the HL technique that resulted in a distance that was significantly shorter than the matching distance on the master model. In conclusion, plastic trays produced less accurate impressions than metal trays. When metal trays were used, putty based impressions were dimensionally better than heavy/light body impressions. Consequently, tray rigidity and control of the bulk of the impression material improved impression reliability.

CHAPTER 1
INTRODUCTION

During the past few years, there has been a tendency to use plastic stock trays rather than custom made trays to make impressions for crowns, bridges and implants. In addition, these plastic trays have been used in combination with different materials of different viscosities. Tray rigidity and material thickness are among many variables that have been described as important factors in making accurate impressions (13, 14, and 15). It has been recognized that the tray should be rigid enough to stand the forces generated during the impression procedures without distortion (50). Regarding the material thickness, it has been said that a thin even layer of 2 mm impression material produces the most accurate impressions (43). Two widely used impression techniques consider or completely ignore these two variables. One uses a metal tray with putty and light bodied material in a two step technique (our group 6) (34), the second uses plastic stock tray with heavy and light bodied material in a one step technique (our group 1)(8). In this study, we decided to test the hypothesis that higher tray rigidity and better bulk impression material control (2 mm space) would produce more accurate impressions by performing intra and inter abutment measurements.

We hypothesized that by using more rigid trays and better controlling the impression material thickness, the precision of an impression would improve. To test our hypothesis, a master model simulating replicas of two abutments of a four unit posterior bridge was used. Two tray types and three different impression material thicknesses were evaluated. Only polyvinyl siloxane impression material was used. Ten impressions per group were made, and the distances between fixed points on the master model and the impressions were measured. Matching distances between the different groups were then compared by using t-test and pair wise comparisons to determine whether significant differences ($p<0.05$) existed in distortion among the two tray types, the three impression thicknesses, or whether there were any interactions between tray types and impression thicknesses. The null hypothesis we tested was that neither tray rigidity or impression thickness had any significant impact on the dimensional reproduction ability of a PVS impression material.

CHAPTER 2
LITERATURE REVIEW

Impression materials are used to register or reproduce the forms and relationships of teeth and oral tissues. Their purpose is to create an exact replica of the oral tissues and then pour the impression with a model material such as stone, on which precise reconstructions can be made in a laboratory environment (11). Today, the most commonly used impression materials for precise reproductions are the non-aqueous elastic impression materials. These materials can be divided into two main groups – condensation and addition polymerized elastomeric impression materials. Of these materials, the addition polymerized elastomers are more stable over time, and are therefore now the materials that are most widely used in fixed prosthodontics (43). The addition polymerized elastomers include addition silicone (PVS) and polyether, two materials well known for their accuracy and dimensional stability (24, 15).

Many factors affect the accuracy of impression materials. These factors include; impression material selection (56), impression material manipulation (8), impression tray design (46), impression retention to impression tray surface (48), impression material thickness (15), tray deformation potential (3), impression technique (the introduction of endogenous tension), impression removal (42), thermal changes after removal (23), storage condition after removal, and material used for making the dies and its compatibility with the impression material. By considering all these variables and how they interact with each others, it becomes clear that impression accuracy is a multifactorial phenomenon. These variables interact sometimes in a positive way and sometimes in a negative way making it quite complex to predict the final outcome.

The trend to use stock trays rather than custom made trays have continuously increased during the past 20 years (7). The reason behind that change relates to improved dimensional stability of polyether (introduced during the mid 60s) and PVS (introduced in the mid 70s) impression materials. Stock trays reduce the number of steps needed to make a final impression. In addition, between plastic and metallic stock trays, there is a strong preference for the plastic ones, because they are disposable (don’t need to be returned from the laboratory) and don’t need to be cleaned and disinfected after use. An important question, though, is whether there are any significant differences in precision between impressions made with custom trays or stock trays. Based on the popularity of the stock trays, it does not seem that the transition to these trays from individual trays have made any clinical significance. Two important variables must be considered regarding tray selection. First, the space allowed between the tray and the prepared teeth and second, the tray rigidity. The tray should be rigid enough to resist forces developed during impression procedures without permanent deformation.

Because of these considerations, as well as the design of this study, this literature review will focus on 4 main topics:

1. 1. Custom vs. stock trays
2. 2. Tray material and dimensional stability
3. 3. Impression techniques
4. 4. Laboratory models used to test impression materials accuracy

Custom vs. Stock Trays

Custom trays are trays specially designed for an individual case. They provide a uniform thickness of the impression material and often reduce the amount of impression material needed. Stock trays are the trays that come in predetermined sizes. They may be either in metal or in plastic. The term “stock tray “ is used in the literature independent of whether the trays are made of metal or plastic. However, it is important to differentiate between metal and plastic stock trays, because the accuracy of metal and plastic stock trays can differ because of differences in their rigidity. Also, the use of stock trays, independent of tray material, results in an uneven bulk thickness of the impression material, which increases the risk for distortion (18, 14, and 15). Therefore, custom trays are recommended to create a thin, even space between the tray and the teeth to control the impression material thickness. When such trays are made, a maximum space of 2 mm is often recommended (14). In studies by Reisbick and Matyas in 1975 (37), thicknesses in the range of 2 to 4 mm were recommended, while Asgar in 1971 suggested 3 to 4 mm (1). According to Nogawa in 1968, differences in thicknesses ranging between 1 and 5 did not produce significant differences, at least as long as the impression is poured immediately after it has been made (33). Eames *et al*. (14) studied the effects of 2, 4, and 6 mm space on the accuracy of 9 elastomeric materials and found that 2 mm space produced the most accurate impressions. De Araujo and Jorgensen (12) in 1985 studied impression material thicknesses and undercut sizes and how they affected PVS material and found that better accuracy was generated for lower impression thickness values (1 mm) and smaller undercuts (0.5 mm). In their study it was clear that 1 mm PVS thickness was better than 2 or 3 mm thicknesses. Apparently, de Araujo *et al*. findings suggest that one should use thinner rather than thicker layers of PVS impression materials. A potential weakness, though, with such a conclusion is that the risk for permanent deformation increases during impression removal if the impression thickness is too thin. Tjan *et al*. in

1992 (47) used custom trays with impression material spaces of 2, 4 and 6 mm, to study changes in the precision of PVS impressions of abutment replicas for a 3 unit bridge.

They found good accuracy in intra abutment dimensions for the four PVS materials used, but distortion in the inter abutment distance existed for two of the impressions poured at different times after impression making. No explanation for that finding was discussed in that article. A possible explanation behind the somewhat conflicting results seen in the literature in relation to material thickness control; may simply be related to the magnitude of recorded undercuts. During impression removal, larger undercuts will increase the deformation of the impression material. According to Hooke's Law, stress is defined as modulus of elasticity times strain, where strain is defined as change in length divided by original length. Thus, if the material thickness is thin and the undercut big, extensive strain will be induced which may raise the stress level to a level where permanent deformation starts occurring. Accordingly, larger undercuts require thicker impression thicknesses. However, as that thickness increases, material shrinkage starts playing a more significant role. Therefore, depending on the size of the undercuts, different errors (plastic deformation vs. material shrinkage) will dominate the final outcome. Consequently, the conflicting results are likely caused by different experimental design approaches.

Other studies have shown that tray space does not have any effect on the intra abutment dimensional accuracy of monophasic polyvinyl siloxane impressions, however, the inter abutment dimensional accuracy is affected (47). Because the dimensions of the abutment replicas are small in comparison to the whole master model, differences in distances are much smaller on the abutment replica than on the full arch impressions. As a consequence, it is much more difficult to identify significant differences on an abutment than between abutments that are far apart, and the rather small intra abutment differences may not be big enough to have any clinical significance. On the other hand, replications of big spans between abutments may result in impressions with small dimensional deviations. Other factors that add to such errors include variations in tray dimensions, expansion/contraction of model material, and last, but probably not least important, differences in operator techniques. All these factors may become noticeable during measurements. Obviously, such measurable dimensional changes would have bigger impact clinically than the smaller intra abutment errors. A factor affecting the accuracy of the inter abutment distances is the flexibility of the tray and its dimensional change when it is removed from the master model as expressed by Gordon *et al*. in 1990 (19).

Not all studies confirm the importance of impression material thickness and tray rigidity. Valderhaug and Floystrand in 1984 (49) compared the accuracy of c-silicone and polyether using custom and metallic stock trays to create impressions of master models. They did not find significant differences in accuracy of impressions made with custom trays or metal stock trays with the two materials. Questions arise from that study because it is well known from laboratory studies that polyether is much more accurate and stable over time than c-silicone and the fact that the measurements did not show any difference between the two materials raises some doubt regarding the validity of that study. The times at which the measurements were made on the impressions were 0 h, 1 h, and 24 h after impression making, and because it is known that a low viscous polyether shrinks about 0.24% during a 24 h period and a low viscous c-silicon shrinks about 0.6% (11), one would expect to see a difference. In Valderhaug and Floystrand’s study (49), the authors did not find any significant differences in inter abutment distances using either tray, even thought ample amount of material was used (2 to 9 mm). Despite Valderhaug and Floystrand's (49) claim that 2-9 mm thick impression materials layer did not have any significant impact, it is generally believed that elastomeric impressions are more accurate in uniform, thin layers of 2 to 3 mm thickness (41). A possible explanation for Valderhaug and Floystrand's (49) claim may have been given by Bomberg *et al*. in 1985 (2), who reported that the mean difference in material thickness between custom trays and stock trays is less than 1 mm, and that variations in uniform impression material thickness exist in both custom and stock trays. The precision of the instruments used to measure changes could be another reason why Valderhaug and Floystrand (49) could not find any differences. Rueda in 1991 (38) did not find any clinical significant differences in impressions made from custom or plastic stock trays. Again, the biggest distortion (>50 µm) was found in the distance between left and right molars. No comments regarding custom tray rigidity were presented in that study. A possible explanation could be that both custom and plastic stock trays had the same rigidity. Dixon *et al*. in 1994, (13) advocated 3 to 4 mm of custom tray thickness to produce enough rigidity to stand impression forces.

One factor that seems important in most studies where fixed partial denture abutments have been replicated is that custom trays should control the impression material bulkiness around abutments and pontic areas. Failing to do so leaves a great amount of material suitable for setting contraction and thermal changes. If a uniform thickness of material is required with a custom tray, attention should be paid to the pontic areas so these regions receive 2 mm of impression material as well. This is important to consider, because this might be the reason why some studies that compare stock and custom trays impression accuracy cannot find any difference between them.

Inter abutment accuracy becomes even more important when implants are used as abutments. Small abutment discrepancies are not as critical when one is working with natural dentitions, because the periodontal ligament could help to compensate for smaller impression errors. Even the die spacer used to build the fixed partial dentures could help. With implants the tolerance is lower. Burns *et al*. in 2003 (5) evaluated the accuracy of implant impressions in vitro using rigid custom open trays and polycarbonate stock trays and found significant differences among groups in the vertical fit of the casts. Custom trays performed better. Vigolo *et al*. found in 2004 (51) that joining the impression copings with Duralay resin for implant level impressions is more accurate than not doing so. Even though they used custom trays for the experiments, they probably were not rigid enough to avoid the distortion produced during the impression procedures. The cross arch accuracy achievable with customized trays is highly desirable to capture multiple implant positions that will be joined by a metal superstructure. Passivity, less solder joints and/or remakes would be the immediate benefit of using more precise impression techniques.

It can be concluded from this review that stock trays probably provide sufficient accuracy for single tooth restorations, particularly if polyvinyl siloxane or polyether are used. However, if one piece fixed partial denture of three or more units are to be fabricated on the cast, the inter preparation and cross arch discrepancies from stock tray impressions could have a significant impact on the fit of the restoration (43, 6).

Tray Material and Dimensional Stability

Other important variables in impression accuracy are related to the rigidity and dimensional stability of the tray. The tray should be stiff and stable enough so it does not deform during insertion and retrieval of the tray-impression complex from the mouth. Any tray deformation, particularly elastic deformation, will result in distortion errors. Metal trays are more rigid than plastic trays. Among plastic trays there are different levels of rigidity. Valderhaug and Floystrand (49) found no differences between impressions made with metal stock trays and rigid resin custom trays. This finding is somewhat surprising if we consider the differences in modulus of elasticity between metallic tray materials and plastic tray materials where the modulus of metal tray materials is around 50 times higher than that of plastic trays. It is possible that by using thick custom trays (4 mm), as the ones advocated by Dixon *et al*. in 1994 (13), the rigidity of a plastic tray can be enough to withstand the forces involved in impression seating and removal, and therefore producing similar results as with metal trays.

Millstein *et al*. in 1998 (30) studied casts made from the use of three different stock trays and a custom tray. Two plastic stock trays, one metal stock tray, and one custom tray were used. Casts produced from the custom tray were more precise and significantly different from the ones produced with the other two trays. Metal stock trays were more accurate than plastic trays. Tjan *et al*. in 1981 (48) published a paper that emphasizes the importance of rigid trays for elastomeric impressions. They reported a research project in which crowns were constructed on 15 working casts made from impressions of a full crown preparation on a typodont (plastic replica of a dental arch). Impressions were made in rigid stock trays, disposable trays and reinforced disposable trays. Not one of the crowns made on the cast dies produced from impressions made with disposable trays fit the master die. All ten of those made on the models from impressions made in rigid or reinforced trays were assessed as satisfactory.

Gordon *et al*. in 1990 (19) compared the dimensions of working casts made from impressions made in either custom trays (using two different tray materials) or plastic stock trays. They found that the plastic stock tray which was much less rigid, consistently produced casts with greater dimensional change than the two custom tray systems, and concluded that the use of plastic stock trays should be limited to the reproduction of casts where great accuracy is not needed. Mitchell and Dammele in 1970 (29) investigated the distortion caused by various tray types with reversible and irreversible hydrocolloids, polysulfides and silicones. They found that tray form had a significant impact on the amount of impression distortion by all materials tested, most seriously with the polysulfide and silicone elastomers and least with reversible hydrocolloid. Even irreversible hydrocolloid exhibited distortion when used in non rigid trays. Carrotte *et al*. (9) studied the influence of the impression tray on the accuracy of putty wash impressions. For that purpose an ivorine model with 3 crown preparations, one for a crown and two for a FPD was used. Four stock trays were tested (3 plastic and 1 metal) with two putty viscosities (heavy and soft). Master model casts were seated on duplicate models and discrepancies were measured. The metal tray and the most rigid plastic tray produced the best fitting. In relation to metal stock trays, Heartwell *et al*. in 1972 showed no difference in the dimensions of casts poured from irreversible hydrocolloid taken in perforated or non perforated metal rim-lock trays (20). Gordon *et al*. in 1990 (19) found that the inter preparation distance (simulation of edentulous areas for a FPD) in casts made from polysulfide, polyvinyl siloxane, and polyether impressions was 45 - 100 μm greater when stock trays were used instead of custom acrylic resin or thermoplastic trays.

They also found 260 µm cross arch discrepancies, which they attributed to stock tray flexibility (19). Similar results in inter abutment distance distortion have been reported (43) for hydrocolloids, C-silicones, polysulfide, and polyether. Stauffer in his study concluded that none of the tested materials was capable of producing a complete arch fixed partial denture on a cast poured from one single master impression (43). However PVS was not tested in that study. Wasell *et al*. (52) and Saunders *et al*. (39) in two separate studies in 1991 showed that reinforcement of stock trays improved the quality of the impression, but did not eliminate completely the distortion from tray deformation. The forces generated during impression procedures are such that even metal trays show changes in dimension intra arch and cross arch. Cho *et al*. in 2004 studied cross section and cross arch changes of six disposable plastic trays and compared them with a metal stock tray (10). Impressions of a plastic model were done using a putty material. Distortion in both across arch and cross section directions was found for the six plastic trays. Metal stock trays showed significantly less change than plastic trays (10).

To reduce inaccuracies in the impression the aforementioned phenomenon should be eliminated or minimized as much as possible.

Dimensional changes of the tray can also occur due to the custom tray material behavior. The tray must remain dimensionally stable over time (3). Because of that concern, the dimensional stability of auto polymerizing acrylic resin tray materials has been the subject of many studies. These studies have resulted in recommendations suggesting that the trays made of auto polymerizing acrylic resin should be made at least 20 to 24 h in advance to avoid major dimensional changes in the material (37). Other studies suggest times from 40 min to 9 h (44, 35). It is well demonstrated on Pagniano’s study that auto polymerizing resins will keep changing even after 24 h (35). Some authors have different recommendations under the assumption that after the first hour of the tray resin setting, most of the dimensional changes have occurred. They believe that the impression can be taken but it should be poured immediately because according to them, the stone would counteract the dimensional changes ongoing in the tray. No other study could be found supporting this idea. In the study by Pagniano *et al*. in 1982 (35) the linear dimensional change of acrylic resins used in the fabrication of custom trays was studied. Four commercial materials were tested for linear changes during 24 h. The results of this study showed that all the materials changed for a period up to 24 h. The most rapid linear dimensional shrinkage of all the materials occurred in the first hour after mixing, varying from a mean change of 0.08% to 0.33%. During the first hour 50 % of the total change that occurred for the 24 hour period had occurred in each of the materials. Pagniano *et al*. (35) recommended to use the tray for the impression after 9 h of setting because at that time most of the total shrinkage had occurred and once made, to pour it immediately to avoid further changes (in resin tray) that would affect its accuracy. Studies on visible light curing (VLC) resins have indicated that these tray materials largely eliminate the disadvantages associated with auto polymerizing resins by improving stiffness, form, and volume stability and by reducing sensitivity to moisture.

The reason for this is basically that the VLC material is similar to the light-cured composites that instead of using an inorganic filler it uses an organic filler (34). The filler consists of acrylic resin beads of varying sizes that become part of an interpenetrating polymer network structure when cured. The VLC material can be used immediately after fabrication (34). It is important to consider this difference among both materials because if they are used at the appropriate time, the mechanical properties are quite similar and good results can be accomplished with either one. Breeding *et al*. (3) studied the mechanical properties of one polymethyl methacrylate, one light polymerizing and three thermoplastic resins used as custom tray materials. The polymethyl methacrylate resin exhibited measured mechanical property values that were significantly higher than those of the thermoplastic resins tested. Small differences in mechanical property values between polymethyl methacrylate resin and light polymerizing resin (Triad Tru Tray) were found. Even though they were statistically different they were too small to be clinically important. The different thermoplastic resins had different mechanical property values among them.

The importance of the rigidity and the mechanical properties in general of the trays was highlighted in an article by Dixon *et al*. published in 1994 (13) when they determined the amount of force needed to remove a tray with impression material from the mandibular arch. They found that the force used was higher when three evenly distributed point forces were used on the tray (514 N) than when the force was placed at a single anterior point (224 N). The amount of force needed when using three points seems to be too much clinically. No other similar studies were found to compare

their results. Those findings showed that the mechanical properties of the materials such as polymethyl methacrylate resin and light polymerizing resins in an appropriate thickness (2.5 to 3 mm) were good enough to resist permanent deformation when subjected to removal forces created under both situations. The authors concluded that thermoplastic resins need to be approximately 4 mm thick to avoid deformation during tray removal (31).

In the light of today's scientific knowledge it is recognized that the dimensional stability and the rigidity are two important characteristics to consider when fabricating customized trays. Auto polymerizing polymethyl methacrylate resins are stable after 24 hours of fabrication and rigid enough at 2.5 to 3 mm thickness. VLC urethane dimethacrylate resins are stable enough immediately after light curing and require the same minimum thickness to assure rigidity. When a stock tray is to be used, metal trays, either perforated or non perforated, produce accurate impressions due to their ability to resist deformation during the impression procedure.

Impression Techniques

Many impression techniques are used but very few are well understood and supported by research. Wöstman in 1997 (56) described 9 impression techniques that pretty much cover all the techniques available. Below are descriptions of the 9 impression techniques.

Correction Impression: Use of A- or C-silicone in combination with the correction impression technique is the most commonly used technique in West Germany. After the teeth have been prepared, an impression is made with a knead paste. A perforated metal stock tray is recommended. Flexible plastic trays are extensively deformed during impression making by the high viscosity paste. As a result, an uncontrollable distortion of the entire impression occurs. Individual trays and stock trays made of plastic are useless for this technique. The success of the correction impression depends on the first impression. The risk is deformation of the first impression when the second is made with the wash material. There is also the risk that the wash does not bond properly to the first impression. The dies produced with this technique are in general too small but the author suggests that the compression impression technique produces clinically useful impressions.

Double Impression: This technique is a variation of the compression impression technique. In this case, the first impression is made before the teeth are prepared. The second impression is made after the teeth have been prepared and that impression is made with a thin flowing impression material that now fills the space that has been removed during preparation. With such an approach, much lower compression is introduced during final impression making. It has also been suggested to make the first impression at least one day in advance to let that material shrink completely before the final impression is made. By storing the first impression for some time before the second impression is made, the rigidity of that material is increased. As a result, impression changes decrease. (56)

Segment Impressions: For this technique the first impression is divided into several segments. It is also a two step technique. Like the first two techniques, this is a modification of them. After the first impression is made, escape furrows are cut to let the material escape lingually or buccally. With this technique it is also possible to reduce stresses that are easily introduced in the correction technique.

Double Mix Technique: With this technique high and low viscosity materials are used simultaneously. The low viscosity is placed on the teeth and the high viscosity material in the tray. In comparison to the correction technique, the double mix technique should have the potential of being more precise because it should not induce the same amount of impression and tray deformation as the correction technique. The key problem with this technique is instead that a delay in the complex process may result in some material setting that in turn can induce residual stresses. Such stresses, when relaxed, result in a somewhat smaller luminum.   Besides, this technique tends to be unreliable when it comes to forcing the material down into subgingival regions.

Sandwich Technique: This technique is a variation of the double mix technique. However, with the sandwich technique, the low viscosity impression material is not injected with a syringe tip around the prepared margins, just placed on the preparations with a mixing instrument (can be described as the "butter and bread" technique). This technique does not reproduce well subgingival regions.

Hydrocolloid Impression: These impressions can be described as being in principle similar to the double mix impression technique. Instead of a silicone or a polyether, hydrocolloid agar is used. The key drawback with this technique is the need for special equipment and more strict preparation. To plasticize the material a special heater is used. The impressions are taken in specially designed water cooled trays. Advantages of the technique include the comfortable use, the low material cost and the consistent outcomes. A significant limitation, though, is the problem to record subgingival margins.

Single Phase Impression: With this technique a single material viscosity is used, and some of the material is injected around the teeth. The use of stock trays with this technique results in poor compression. This technique can be improved by use of a custom made tray. Polyether is the most commonly used material with this technique. By use of the single phase technique combined with a custom made tray and an A-silicone or a polyether impression material, it is possible to produce very precise impressions.

Shrinkage and distortion effects caused by endogen stress play a minimal role with the single phase impression technique.

Ring Impression (Copper bands): Ring impression with a thermoplastic compound is one of the oldest used impression methods. Today this technique has been replaced by more modern techniques. When the ring impression technique is used, only one tooth is imprinted in each ring impression.

Optical Impressions: Since 1971 attempts have been made to generate numerical information of the teeth. The first successful attempts were introduced by Duret, Rekow, Mormann, and Brandistini (56). One of the systems available (Cerec) consists of an intraoral camera that records the prepared tooth surface, then the computer converts that information to an x, y, z coordinate system. Then a milling machine produces the restoration from these coordinates.

Impression Technique Studies

Gelbard *et al*. (17) studied the effect of two impression materials used with three different techniques in order to address the marginal fit of metal castings. The following methods were used to make the impressions: 1) putty/ wash in one phase with metal tray, 2) copper band relined with auto polymerizing acrylic resin and subsequent light body elastomeric impression material, 3) copper bands with modeling compound. Metal copings were fabricated from casts made out of the impressions, seated on master die models with pressure indicator paste and then cemented.

Master die and coping were cut in half bucco-lingually and measured under the microscope to evaluate the marginal fit. Measurements of the thickness of the cement layer were calculated manually and with a computerized method. The metal castings fit were from 38.3 μm to 128.4 μm for both the methods of measuring. Gelbard *et al*. (17)

claimed no superiority of any of the impression techniques. Newman *et al*. in 1986 investigated the dimensional stability of various impression techniques using different impression materials. Their concern was to determine if different techniques would cause different degrees of dimensional changes with different impression materials. Six polyvinyl siloxane materials and one polyether material were shown to be dimensionally stable, while the two polysulfide materials were not stable. The single viscosity custom made tray impression technique gave consistently greater degree of error with both polysulfide and polyvinyl siloxane impression materials, while the putty-wash technique gave consistently more accurate fits with either a one step or a two step technique. One widely used technique is the technique that uses light body in the syringe and heavy or medium body in the tray (8). Johnson and Drennon in 1987 conducted a clinical evaluation of detail reproduction of elastomeric impression materials. They concluded that the double mix technique produced better detail than did the single mix technique. Heavy consistencies, rather than medium, in combination with a light consistency material resulted in better details. Another technique is the putty-wash technique, which was developed to compensate for the polymerization shrinkage of the condensation silicones attributed to the production of an alcohol byproduct during polymerization (29). The two step putty/wash technique used a thin layer of wash material that minimized the amount of alcohol byproduct and thereby retained the dimensional stability within acceptable limits (37).

Although the putty wash technique was originally recommended for problems associated with polymerization shrinkage of the c-silicones, this technique has also been suggested for a-silicone impression materials (36).Two variations of the putty wash method are commonly used: the putty/wash one step technique, in which the materials polymerize in one stage and the putty/wash two step technique, in which a putty is first used alone as the initial step and then a final impression is made within the putty material by use of a silicone of lower viscosity (22). Idris *et al*. compared the accuracy of the one step and two step technique using a-silicone impression material (22). For the purpose of the study they used three stainless steel replicas of abutment, one die without undercuts and two with undercuts. Grooves were prepared on the occlusal surfaces for measuring purposes. Impressions were taken using perforated metal trays. All impressions were poured and then measured under the microscope. Inter abutment distances increased for all but one measurement in comparison to the master model for both techniques. Almost all intra abutment distances were smaller than the ones on the master model. An explanation for these results could be that smaller dies (smaller intra abutment distances) may create bigger inter abutment spaces. The smaller dies are supposedly the result of the hydraulic pressure created while seating the one step or two step techniques with the materials in place. Idris *et al*. consider that the differences found between the two techniques were not of clinical significance. Differences of about 32 µm for spans 40 mm long are not of clinical significance as long as mobility exists in the periodontal ligament. The authors concluded that neither technique resulted in dies that deviated sufficiently from the master model to cause clinical difficulties (22).

Nissan *et al*. studied the putty wash techniques but the two step technique was further divided in two different approaches. The three approaches were: 1) putty/wash in one phase, 2) putty/wash with 2 mm metal coping spacer in two phases, and 3) putty/wash with polyethylene spacer in two phases (32). A metal master model, containing three complete crowns fixed partial denture abutment preparations with grooves on the occlusal surfaces, and perforated custom trays were used. Impressions were made at room temperature and then poured in stone. All measurements were done using a Toolmaker's microscope. As in Idris *et al*. study (22), Nissan *et al*. (32) found increases in inter abutment distances (0.009% to 0.1%) and decreases in intra abutment (0.08% to 3%) distances. They found significant differences among the three groups. The second group was the most accurate of the three groups.

The authors criticized the one step technique because it reproduced a part of the margins in the putty material, which they claimed had not enough detail reproduction to produce a reliable casting. The question, however, is whether it is only putty on the margins or that the light body is so thin that it cannot be seen. Most putties on the market cannot reproduce details fine enough to meet the American Dental Association (ADA) specification 19.

Laboratory Models Used to Test Impression Materials Accuracy

Research into impression accuracy has relied heavily on in vitro tests rather than clinical evaluations. The key reason is simply that clinical studies are difficult to standardize and reproduce. For example, variables such as tray flexing/recoiling ability and differences in impression techniques are difficult to eliminate clinically. Also, it is easier to make measurements in the laboratory than in the mouth (53). However, the drawback with most laboratory tests is that such studies do not simulate the true oral conditions very well. Some tests provide realistic tooth morphology, arch form and temperature control but none of them mimics soft tissue consistency or the surface characteristics imparted by the oral fluids (53). The presence of oral fluids under clinical conditions is important to emphasize, because some of the “best” materials according to laboratory evaluations are also the most hydrophobic materials. Consequently, materials that seem to be superior in a laboratory environment may still be inferior in a clinical situation because they cannot reproduce a moist dentin surface. Under such conditions a material that may be inferior in laboratory evaluations may still be superior in clinical situations. Being well aware of the laboratory/clinical conflicts, the following review will target those variables that might influence the results of our study.

Master Model Material and Abutment Replica Design

Many models have been used by researchers to test impression materials. Stauffer, *et al*. use an aluminum master model machined with four prepared abutment teeth of stainless steel positioned in a maxilla (43). Undercuts were not taken into consideration. All four teeth were cylindrical and parallel to each other and all vertical walls had 5° taper. Evaluations of the resulting casts were made by comparison with a master fixed partial denture. Metal (stainless steel, chrome steel, aluminum, and cooper) has been mainly used because it resists wear during laboratory work. Metal is also less susceptible to accidental damage and its coefficient of thermal expansion is small enough to resist master model changes during experimental simulation of oral temperatures (35-37°C). Another important consideration is the availability of stainless steel material at the engineering department laboratories at different universities where similar studies can be conducted. Eames *et al*. used stainless steel dies with 12° taper to evaluate the effect of the bulk of the impression material on the accuracy of impressions (14). Marcinak and Draughn (26) prepared two maxillary central incisors mounted in an acrylic resin block. The distal surfaces were machined precisely parallel to each other to provide accurate measurements. Valderhautg and Floystrand (49) tested the materials using two models with stainless steel standardized abutment teeth in the area of the canines and the first molars. The teeth were drilled with a taper of 10°. Two grooves 5 µm wide were engraved at right angles in the center on the occlusal surfaces. De Araujo and Jørgensen (12) used a truncated chromium steel cone die with and 8 mm base diameter and 8 mm in height. The die was undercut apical to the gingival margin. Three rings were used to create three different undercut heights. Johnson and Craig (24) tested four rubber impression materials using a stainless steel master model simulating two full fixed partial denture abutment preparations. The preparations were 10 mm in height and 10 mm in diameter, and one of them had an undercut with an 8 mm diameter. Lin *et al.* (25) prepared four abutment teeth from a dentoform for complete crowns with 1 mm shoulder margins by using a handpiece mounted in a parallel instrument. The height of the canine tooth preparation was 8 mm and the molar was 7 mm. Saunders *et al*. (39) used a dentoform with prepared teeth as a master model to test the effect of impression tray design and impression technique on the accuracy of the resulting casts. A copper plated master model was used by Wasell and Ibbetson (52) to evaluate the accuracy of polyvinyl siloxane impressions made with standard and reinforced stock trays. Tjan *et al*. (47) also used stainless steel dies to create the master model for their study. They created a model simulating a three-unit fixed partial denture. Reference lines were inscribed on top and axial surfaces of the abutments to assess the dimensional changes. In conclusion, most of the studies have used stainless steel to create the master models. Others have used natural teeth, plastic teeth, copper plated or chromium steel models. Metal bases as well as metal dies are much more dimensionally stable to thermal changes while simulating oral environment (35°C to 37°C) than the plastic ones. On the studies reviewed, 5° to 12° taper were used as total occlusal convergence for the abutment preparations replicas.

Undercuts are another important variable to consider when testing impression materials. Larger undercuts are more difficult to imprint precisely.

Methods to Seat the Tray

Another important variable is the way the tray is seated against the master model time after time. It is necessary to do it the same way every time an impression is made, and therefore a standardized technique is required. To verify the importance of standardization in seating the tray, a simple exercise was performed at the University of Florida, Graduate Prosthodontics clinic with three residents. All of them were asked to make an impression of a resin mandibular model using the heavy/light body technique. Using a scale the amount of pressure was measured while the impression was made. The lowest amount of pressure was 2 pounds and the highest 15 pounds. No studies could be found in relation to this variable but some differences in material behavior are supposed.

The use of alignment pins that guide the tray during seating is a common method to achieve this goal during laboratory experiments (43, 24, 49, 13).

Table 2-1 Variables related to some of the studies that have used abutment replicas to test impression material accuracy.

Marcinak et al.	1982	2 teeth,acrylic	prep. parallel	0	yes
Valderhaug et al.	1984	SS and Al	4abutments 2 models	10	yes/no
de Araujo et al.	1985	Cr steel	single die 26.5 degree undercut	5	yes
Jhonson et al.	1985	SS	2 dies in a block	6	yes
Lin et al.	1988	Plastic	4abutments Max model	n/a	no
Gordon et al.	1990	SS and Plastic	2 abutments 3 metal inserts	n/a	yes
Wasell et al.	1991	Copper plated model Dentoform	3 abutments copies of a dentoform	n/a	no
Saunders et al.	1991	Plastic	2 FPD abutments 1 inlay opposite side	n/a	no
Tjan et al.	1992	SS	2 FPD abutments mounted in a plate	n/a	no
Hung et al.	1992	SS	2 FPD abutments mounted in a plate	n/a	yes
Gelbard et al.	1994	Plastic	Ivorine prepared tooth mounted in a dentoform	n/a	no
Idris et al.	1995	SS	3 abutment replicas triangular distribution Occlusal grooves	n/a	yes
Millstein et al.	1998	SS	4 abutments. 2 anterior 2 posterior. U shaped bar	5°	no

Table 2-1. Continued

AUTHOR	YEAR	MATERIAL	ABUTMENTS	TOC	UNDERCUTS
Carrote et al.	1998	Stone dentoform Ivorine teeth	1 full crown and 2 abutments for PFM	5°	no
Nissan et al.	2000	3 SS preparation replicas	3 full crown preps in small metal block	n/a	no
Thongthammachat et al.	2002	Metal master model	Multiple prepared teeth. 8 reference holes, 3 reference points.	n/a	no
Wadhwani et al.	2005	Modified dentoform Metal inserts on 1st molars and lower incisors	Metal inserts and a removable die	12 °	no

Table 2-2 Variables related to some of the studies that have used abutment replicas to test impression material accuracy (cont)

AUTHOR	YEAR	TEMPERATURE	IMPRESSION MATERIAL
Stauffer et al.	1976	35 °C and 12 °C	2 hydrocolloids, 1c-silicone
			2 polysulfides,1polyether
Eames et al.	1979a	37± 2 °C	3 polysulfides, 2 polyethers
			2 c-silicones
Eames et al.	1979b	32 ± 2° C	2 polyethers, 8 c-silicones
			2 a-silicones, 5 polysulfides
Marcinak et al.	1982	37° C	5 a-silicones
Valderhaug et al.	1984	21° C	1 polyether, 1c-silicone
de Araujo et al.	1985	37° C	1 polysulfide, 1a-silicone
Jhonson et al.	1985	25° C	1 a-silicone,1polysulfide
			1 c-silicone,1polyether
Lin et al.	1988	n/a	2 polyether, 2 a-silicones
			2 polysilfides, 2 reversible
			hydrocolloid, 2 irreversible
			rev -irrev combination
Gordon et al.	1990	34° C	1polyether,1 a-silicone,1polysulfide
Wasell et al.	1991	23° ± 1° C	PVS H/L and P/L techniques
Saunders et al.	1991	37 ° C	PVS P/L 3 techniques: P/L 1 stage,
			P/L in 2 stages creating space with
			an scalpel, and P/L creating space
			with spacer
Tjan et al.	1992	22° C ± 2° C	Four brands of monophasic PVS
Hung et al.	1992	n/a	Five brands of P/L impression
			material. Tested in one and two stage
			techniques.
Gelbard et al.	1994	n/a	3 groups. 1 P/L in one stage with
			metal tray.2 Copper band relined with
			acrylic and wash material. 3 Copper
			band and impression compound
Idris et al.	1995	Room temperature	P/L one stage and P/L two stages
			PVS material
Millstein et al.	1998	n/a	H/L technique. 3 stock trays and
			1 custom tray

Table 2-2 Continued

AUTHOR	YEAR	TEMPERATURE	IMPRESSION MATERIAL
Carrote et al.	1998	n/a	PVS P/L Material. Putty in 2 viscosities
			normal and soft. One stage technique
Nissan et al.	2000	room temperature	1 step P/L, 2 step P/L with 2mm relief"
			2 step P/L with polyethylene spacer
Thongthammachat	2002	35°C ± 1° C	PVS and Polyether
et al.			
Wadhwani et al.	2005	23° C	Fast set PVS and fast set polyether
			regular setting polyether as control

Table 2-3 Variables related to some of the studies that have used abutment replicas to test impression materials accuracy

AUTHOR	YEAR	TRAY	POURING TIME
Stauffer et al.	1976	custom	5 minutes
		2mm space	
Eames et al.	1979a	custom	0 min
		2, 4, and 6mm	
		space	
Eames et al.	1979b	custom 2.4mm	30min and 24h
		space	
Marcinak et al.	1982	custom, 3mm	10m, 30m, 2h
		space	4h, 8h, 24h,
			48h,96h,168h
Valderhaug et al.	1984	custom 3mm	no stone model
		thick.2 to 4 mm	
		space.	
		metal stock	
de Araujo et al.	1985	custom metal	10min
		1mm, 2mm,	
		3mm, 4mm	
Jhonson et al.	1985	custom 2mm	1h,4h (2 pour)
		thick.3.75mm	24h
		space	
Lin et al.	1988	custom 2mm,	NS
		thick	
		3mm space	
Gordon et al.	1990	2 custom types and 1 stock	1 h
		3mm thick, 2.5 mm space	
Wasell et al.	1991	2 stock trays (plastic)	24 h
		2 reinforced stock trays	
Saunders et al.	1991	Plastic tray without and with	24h
		3 types of reinforcement	
Tjan et al.	1992	Perforated small custom trays	1h, 24h and 7 days
		with 2, 4,and 6mm space	
Hung et al.	1992	Perforated metal tray	1h
Gelbard et al.	1994	Metal tray and copper band	NS
Idris et al.	1995	Metal tray	1h
Millstein et al.	1998	3 plastic and 1 custom tray	0h

Table 2-3 Continued

AUTHOR	YEAR	TRAY	POURING TIME
Carrote et al.	1998	1 metal and 3 plastic trays	NS
		Suupossed different rigidity	
		for all of them	
Nissan et al.	2000	Metal custom tray	1h
Thongthammachat et al.	2002	Metal and plastic stock trays	30 min, 6h, 24h, 30d
		4 types of custom trays	
		2 to 2.5 mm	
Wadhwani et al.	2005	Plastic stock tray	1h

Table 2-4 Variables related to some of the studies that have used abutment replicas to test impression materials accuracy.

AUTHOR	YEAR	MEASUREMENT METHOD	FINDINGS
Stauffer et al.	1976	visual inspection of metal framework	No interarch accuracy found for any
		Dial gauge measurement	material.
Eames et al.	1979a	impression at 0min ,24 h. microscope	2mm space better accuracy, Cast
		Other impressions poured at 0 min.	lifting from 4 and 6mm impressions
		Castings/master die tested on dies	were clinically unaceptable
Eames et al.	1979b	impression at 0min ,24 h. microscope	when poured at 0min all materials
		other impressions poured at30 min.	where accurate. At 24h a-silicones
		and 24h. Castings tested on dies	least change
Marcinak et al.	1982	5 measurements of the die with a	greatest change of 0.3% up to a
		micrometer.	putty wash most unstable. Produced
			smaller dies.
Valderhaug et al.	1984	impressions measured at 0min, 1h	c-silcone and polyether behaved
		24h.linear measurements made only	similar at different time intervals
		microscope used.	no difference between stock and
			custom trays
de Araujo et al.	1985	traveling microscope on stone	increase of material thickness from 1
			to 4 mm increased distortion.
			less distortion when increasing the
Jhonson et al.	1985	traveling microscope on stone	Larger diameter of abutment for a-
			silicone and polysulfide. Vertically
			where smaller in general.siliconese
			were least affected by double pour.
			more distortion with undercut
Lin et al.	1988	master casting joined with resin	Polyethers the most accurate
		seated on casts	complete arch impressions
		measured under microscope	
Gordon et al.	1990	Measurescope, measures up to 1µ	Dies height very accurate for all materials
			width larger for polyether and polysufide.
			PVS very precise
			Interprep distance longer for all, the stock
			trays produced distortion from 45 to 100µ
			Cross arch dimensions with stock trays
			distorted up to 260µ
Wasell et al.	1991	Wild photomicroscope. Measured in mm	H/L technique minimum distortion with
		with 2 decimals	the different trays. P/L high distortion.
			Reinforcement improved P/L accuracy
			but P/L performed better
Saunders et al.	1991	Reflex microscope and computer	None of the trays affected the accuracy of
			the P/L impressions.One stage technique
			one distance significantly different. Two
			stage techniques had also one .
			Results contradict conclusion.

Table 2-4 Continued

AUTHOR	YEAR	MEASUREMENT METHOD	FINDINGS
Tjan et al.	1992	Microscope- quantitative method Master castings- qualitative method	Differences found among PVS brands Tray space and pouring time did not affect accuracy for individual preparations Tay space did affect inter preparation distances. Both methods did not correlate
Hung et al.	1992	Microscope Measurment of stone casts	4 brands produced larger interabutment distances.One stage P/L technique and two were equally accurate. All materials produced larger abutment height
Gelbard et al.	1994	Castings cut sections measured with SEM	No statisically significant differences among the techniques
Idris et al.	1995	Toolmaker's microscope and computer Master model and stone casts measured	In general all interabutment distances increased but one. Intrabutment distances decreased, except for two distances. Significant differences for all interabutment measurements.Not clinically significant
Millstein et al.	1998	Micrometer and a template	Casts from custom trays were significantly more precise than the ones from stock trays. The more flexible trays presented more distortion.
Carrote et al.	1998	Travelling microscope. 3 master castings 3 single crowns	Marginal adaptation for metal or plastic rigid trays is very similar.From 55 to 72 µ For more flexible trays from 137 to 207.5µ
Nissan et al.	2000	Toolmaker's microsocpe and computer	Significant differences among the groups The second group was the most accurate
Thongthammachat et al.	2002	Measuring microscope	No differences in accuracy with different trays. More distortion for polyether Silicone stable up to 30 days and 4 pourings.
Wadhwani et al.	2005	Measuring microscope Stone casts	No differences between disinfected and non disinfected conditions Significant differences among the 3 materials in 4 dimensions. Differences are not sigificant clinically

The amount of load used to seat the tray should also be controlled. Stauffer *et al*. used 9.8 N on top of the tray platform to seat them into position (43). Wassell and Ibbetson standardized the impression procedure using guiding pins and an Instrom testing machine to seat the impression tray (52). The majority of the studies do not control this variable when performing the experiments by hand seating the trays.

Thermal Changes

Impressions reach a temperature of approximately 33°C after being in the mouth for 5 min (23). On cooling to room temperature measurable dimensional changes occur as impression materials have a relatively high coefficient of thermal expansion. A similar rate and amount of impression temperature rise should be incorporated in laboratory tests. At present there is no agreement over the best way to do this. The standardization organizations use water baths at 32°C while other workers prefer 35°C. Another approach is to use a heat source within the master model, but the characteristics of heat flow into the impression has never been specified (55). Stauffer *et al*. tempered the master model at 35°C before making the impressions to simulate the mouth temperature (42). Eames *et al*. used a 37 $\pm$ 2°C water bath to let the impressions harden in it (14). In a different study the same authors used 32 $\pm$ 2°C water bath for the same purpose (15).

Marcinak and Draughn in 1986 stored the natural teeth model at 37°C and 100% humidity just before the impression was taken (26). Johnson and Craig in 1985 allowed the impressions to set at room temperature rather that an elevated oven temperature to avoid expansion of the stainless steel master model with heating (24).

To conclude: Temperatures from room temperature (~ 20°C) to 37 $\pm$ 2°C have been used to reproduce thermal characteristics of the oral environment.

Type of Measurements

Tests can broadly be divided into two main groups depending on whether measurements are made on the impressions themselves or on the resulting casts. In addition, measurements may either be made of the individual dies or the inter die relationships or both (53).

Direct Measurements of the Impression Material: The ADA and BSI bodies both employ a scribed block which is used to form a disc of impression material. Measurements are made between the scribed lines on the block and the resulting lines on the impression discs to give an indication of time-dependent dimensional changes. In addition the scribed lines provide a measure of surface reproduction. Light and medium bodied materials should be able to reproduce a 20 µm wide line (53). A logical use of the standard block method is to inscribe the occlusal surface of a crown preparation with engraved marks like the ones on the standard and measure them within the impression

Eames *et al*. (14) used a similar design to test the accuracy of different impression materials at different thicknesses on the impression tray.

Measurements of Individual Dies: The measurement of dies poured from impressions is clinically a more realistic method of assessing impression accuracy than direct measurement of impression shrinkage (53). This is because the accuracy of the die will determine the final fit of the restoration. In addition it would be difficult to view microscopically the critical cervical part of a preparation within an impression. Type IV die stone is generally chosen because it has a minimal linear setting expansion of 0.1 %. There are some drawbacks involved in this technique. The most important drawback is that it is impossible to know whether it is the cast or the impression that causes the biggest problem. Another drawback is that the detail reproducing ability of die material is poor in comparison with the impression material causing the precision of the measurements to become questionable. To overcome that problem, different methods have been used. Thus comparisons of die measurements with master dies have been done in the following three ways:

1. Assessment of how well castings made on each of the poured dies fit the master die. (55)
2. Assessment of how well a single master casting made on the master die fits each of the poured dies. (55)
3. Linear measurements with contact or no contact methods (55)

Table 2-5 Coefficient of thermal expansion of some of the materials used in the master models (Inlay waxes listed for comparison purposes only)

Material	Coefficient x 10^{-6} /C°
Inlay waxes	350-450*
Silicone impression material	20
Acrylic Resin	76
Stainless steel	5.5-17.6*
Tooth (crown portion)	11.4

*Differences in values for different material composition.

The first method is rarely used. It is time consuming because the number of castings necessary to run a study and at the same time, castings can be another source of errors that are difficult to control. In this technique the amount of lift of the cast is measured under the microscope. The lift of the study metal casting may be influenced by the roughness of the die, the casting, the casting orientation and seating pressure. On the other hand, if the stone die is oversized the cast will seat loose on the master die and no lifting will occur, even though some distortion in size was caused by the impression.

The second method is more widely used. In this case, if the stone die is undersized the cast will seat completely and no lift will be present. Since only one casting needs to be done it is more popular than the previous method. Eames *et al*. (15) used this method in his study. Careful manipulation and standardized seating pressure and orientation are necessary to avoid abrasion of the stone dies and record false lift measurements (closer fitting).

The third method is basically about linear measurements made using contacting instruments such as calipers, vernier calipers or dial gauges, or non contacting measurements like the ones obtained with different microscopes such as the traveling microscopes, toolmaker's microscope or the sophisticated reflex microscope (3D measurements). Non contact measurements are preferred over contact methods because it prevents stone abrasion. The second method, the one that uses one master casting to fit all resulting study dies, assesses the problem from a more clinical stand point including the variable of the casting. It is also more susceptible to three-dimensional changes of the stone dies. On the other hand, many sources of errors are inherently present. The third method, that uses different non contact measuring devices, only analyses linear dimensions of predetermined marks which may lead to loose valuable information. The ideal method would be the one that scans directly the impression and is accurate enough to digitally compare them three dimensionally by volume and superimposition, in other words a combination of methods 2 and 3.

Inter Die Relationships: If a fixed partial denture does not fit, the problem may be caused by distortion of the inter die relationship as well as inaccuracies of the individual dies. Therefore, an important prerequisite of all inter die relationship studies is that the individual dies are not allowed to move within the master model. Different options to measure inter die relationships are described below:

1. Master model and cast master bridge (55)
2. Master model and machined template (55)
3. Contact measurements of inter die relationships (55)

4. Non Contact measurements of inter die relationship
 -Two-dimensional (55)
 -Three-dimensional (55)

The first technique is similar to that used for individual dies except linked master castings are use to fit the abutments. Stauffer *et al*. (43) used a machined stainless steel master model with four abutments of 5° taper representing two canines and two molars. A surveyor was used to align the linked castings to the four dies during seating under standardized force. An average value of lift of the four castings was used to assess impression accuracy. No distinction could be made between the amount of lift due to intra abutment inaccuracies and inter abutment inaccuracy. In this situation the method would not give a good indication of how well a bridge might fit the abutments clinically.

The second technique presents the same issue as the first one, and no distinction can be made between intra abutment inaccuracies and inter abutment accuracies.

The third approach was used by Stauffer *et al*. (43) who used a L shaped device that had gauges to measure changes along the x and y axes of the stone casts and compare these values with those of the master model. This device recorded differences that were difficult to rationalize clinically.

The fourth approach is basically the use of microscopes and the measuring of distances between marks on the master model and impressions. Two or three dimensional measurements can be made, depending on the instrument and the methodology employed to calculate distances.

In conclusion: There are many ways to measure intra abutment and inter abutment impression accuracy. All of them have advantages and disadvantages. The recommended method should be the one accurately assesses the finish line area. Dies poured from impressions produce a more realistic method of assessing impression accuracy but adds the errors caused by the properties of the die material. If measured with non contact devices the detail reproduction of the stones prevents the accurate reading of established marks. Three dimensional measurements of the dies generate better assessments, particularly when non contact measurements are used. Such analysis of 3D digital data was used recently by Brosky *et al.* to determine the effect of impression tray selection on accuracy of reproduction of a dental arch (4).

CHAPTER 3
MATERIALS AND METHODS

This study was designed to determine the importance of material thickness control and tray rigidity on the accuracy of polyvinyl siloxane impressions. To achieve that goal, the following six impression groups were compared in this study.

Impression Groups

The six impression groups were distributed as follows:

1. Plastic stock tray (Disposable impression trays, Henry Schein Inc, Melville, NY, USA) in which heavy and light bodied PVS (Aquasil, Dentsply /Caulk, Milford DE) material were used with the one phase technique. Tray adhesive was applied at least 10 min prior to the impression (V.P.S. Tray Adhesive. Kerr Romulus, MI).

2. Plastic stock tray (Disposable impression trays, Henry Schein Inc, Melville, NY, USA) in which putty (Exaflex, GC America Inc, Alsip, Il) and light bodied PVS (Aquasil, Dentsply /Caulk, Milford DE) material were used with the two phase technique. Compression technique. Tray adhesive was applied at least 10 min prior to the impression (V.P.S. Tray Adhesive. Kerr Romulus, MI).

3. Plastic stock tray (Disposable impression trays, Henry Schein Inc, Melville, NY, USA) in which putty (Exaflex, GC America Inc Alsip, Il) and light bodied PVS (Aquasil, Dentsply /Caulk, Milford DE) material were used with the two phase technique. Space was created with a 2 mm plastic pressure formed template (Great Lakes Company). Tray adhesive was applied at least 10 min prior to the impression (V.P.S. Tray Adhesive. Kerr Romulus, MI).

4. Metal tray (Rim-lock trays, Dentsply-Caulk) in which heavy and light bodied PVS (Aquasil, Dentsply /Caulk, Milford DE) material were used with the one phase technique. Tray adhesive was applied at least 10 min prior to the impression (V.P.S. Tray Adhesive. Kerr Romulus, MI).

5. Metal tray (Rim-lock trays, Dentsply-Caulk) in which putty (Exaflex, GC America Inc Alsip, Il) and light bodied PVS (Aquasil, Dentsply /Caulk, Milford DE) material were used with the two phase/compression technique. Tray adhesive was applied at least 10 min prior to the impression (V.P.S. Tray Adhesive. Kerr Romulus, MI).

6. Metal tray (Rim-lock trays, Dentsply-Caulk, Milford, DE) in which putty (Exaflex, GC America Inc Alsip, Il) and light bodied PVS (Aquasil, Dentsply /Caulk, Milford DE) material were with the two phase technique. Space was created with a 2 mm plastic pressure formed template (Great Lakes Company). Tray adhesive was applied at least 10 min prior to the impression (V.P.S. Tray Adhesive. Kerr Romulus, MI).

Impression Materials

Three impression materials were used for this study. Forty light bodied consistency cartridges of Aquasil Ultra LV (lot # 050421, Dentsply /Caulk, Milford, DE) were used. Forty heavy bodied consistency cartridges of Aquasil Ultra Heavy (lot # 050618, Dentsply /Caulk, Milford, DE) were also used. This material is described as a quadrafunctional hydrophilic addition reaction silicone. Four standard packages of Exaflex (lot # 0505201, GC America Inc Alsip, Il) putty material Type 0 (very high viscosity) were also used during the experiments.

Adhesive was applied on all metal and plastic trays at least 10 minutes prior to the impression. Four bottles of V.P.S Tray Adhesive (lot # 5-1082, Kerr Corporation, Romulus MI) were used.

Master Model

A lower arch master model was made of self curing Orthodontic Resin (Dentsply-Caulk, Milford, DE) with resin teeth from canine to canine and four machined stainless steel dies. The four stainless steel simulating prepared abutment teeth were embedded in region 37, 34, 44, and 47. In addition, two stainless steel reference posts located in the region between 37 and 34, and 44 and 47 were placed at the ridge level. The stainless steel dies were designed to simulate circular full crown preparations with shoulders. The molar die preparations had 6° total occlusal convergence (TOC), were 7.0 mm high, had a cervical outer diameter of 9.0 mm and a shoulder width of 1.0 mm. The premolar dies had the same TOC, height and shoulder width, but an outer diameter of 7 mm. The root portion of the stainless steel dies were 15 mm in length and had a design that well locked them inside the resin to prevent rotation and vertical displacement. Approximately 1 mm of the dies root portion was exposed on all four dies. The two reference rods consisted of two stainless steel rods, 3 mm in diameter, were inserted at the ridge level, halfway between the stainless steel replicas located on each side. A diamond bur (Maxima Diamonds, 801-012C-FG, Henry Schein Inc, Melville, NY, USA), attached to a plan-parallel meter (PFG 100; Cendres & Meraux, Bienne, Switzerland), was used to make marks on the occlusal surfaces and the shoulders of the dies as well as on the stainless steel rods between the dies. These marks under the microscope looked like targets on which the center was the reference for each particular mark.

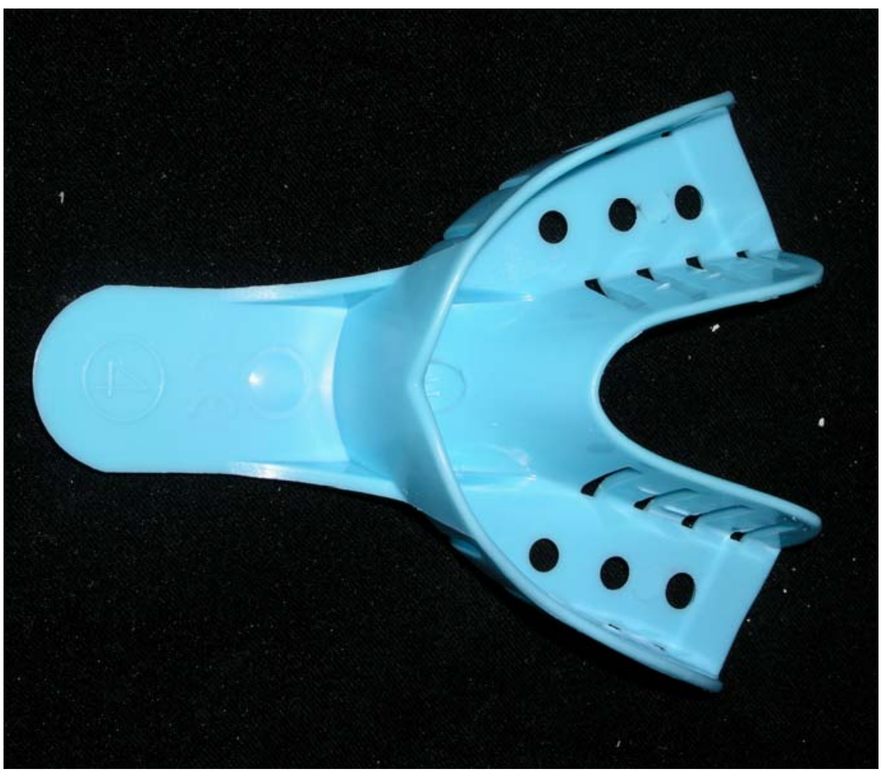

Figure 3-1. Plastic stock tray used for the study (Disposable Impression trays, Henry Schein Inc, Melville, NY, USA)

Figure 3-2. Metal stock tray used in the study (Rim-lock trays, Dentsply/Caulk, Milford, DE, USA)

Figure 3-3. Occlusal view of the master model. Note the stainless steel rods between abutment replicas

Figure 3-4. Frontal view of the master model

Figure 3-5. Buccal view of nine of the eleven marks on the master model with their corresponding numbers (One mark on each occlusal aspect of 44 and 47)

Figure 3-6. Lingual view of the marks on the master model with their corresponding numbers (occlusal marks on 44 and 47)

Figure 3-7. Impression materials used for the study. Aquasil Ultra heavy and light bodied and impression gun (Dentsply/Caulk Milford, DE), Exaflex putty (GC America Inc, Alsip, Il), and V.P.S. Tray Adhesive (Kerr, Romulus, MI)

Table 3-1. Tray rigidity and thickness control for the different study groups

Group	Tray rigidity	Thickness
1	Low	High
2	Low	Minimum*
3	Low	Low*
4	High	High
5	High	Minimum*
6	High	Low*

High Thickness: Represents in this study the Heavy/Light impression technique in which the material thickness is not controlled at all (stock trays used).

Minimum Thickness: Represents in this study the Putty/ Light technique in which the material thickness was controlled using a two step technique without creating space for the second impression.

Low Thickness: Represents in this study the Putty/Spacer/ Light technique in which the material thickness was controlled using a two step technique creating a 2 mm even space for the second impression.

Low Rigidity: Represents the rigidity of the plastic stock trays

High Rigidity: Represents the rigidity of the metal stock trays

The eleven marks location of the metal dies for each side (right and left) were the following: Five marks on tooth 47 abutment one distal, one mesial, one buccal, and one lingual on the 1 mm shoulder, while the fifth mark was on the occlusal surface of the die. Five similarly located marks were present on tooth 44. The eleventh mark was on the metal rod in between tooth 44 and tooth 47 and served as a reference point for the other ten points. In this study only tooth 44 and tooth 47 abutment replicas were used for the experiments.

Impression Making Device

Once the master model had been constructed according to the specifications mentioned before, the next step was to standardize the way the impressions were made. For that purpose, the master model was attached by two screws to a half inch thick aluminum plate. This plate was seven inches long and five inches width. Three stainless steel pins, each one with a diameter of three eights of an inch and a height of five inches, were vertically positioned on the aluminum plate, two in the front and one in the back of the master model.

The three vertical pins on the base plate guided a second plate to which either the metal or the plastic tray was attached. It was necessary to build separate plates for the metal trays and plastic trays. These plates were made in aluminum and had the same dimensions as the previously described base plate. These two top plates with their holes sliding along the rods of the base plate allowed the top plates to slide very precisely onto the master model during the impression procedures. This system controlled the positioning of the impression trays in three dimensions every time an impression was made. Three plastic stops were assembled on the pins in order to control the seating of the tray against the model. Two different sets of vertical stops were built, one set for the metal trays and the other for the plastic trays. Sixty complete lower arch impressions in PVS material utilizing the techniques and trays described for each group were made of the master model. All impressions were made at room temperature (23° to 25°C) and kept at room temperature during the 24 h period before measuring them under the microscope. The humidity where the impressions were stored was between 54 and 56 %. Ten impressions per group were made.

Impression Procedures Sequence and Standardization

The following was the impression sequence followed for impressions made either with plastic or metal trays. An homogeneous thin layer of tray adhesive was applied to all the trays at least 10 min before the impression was made. Different weights were used during impression making because of differences in viscosities of the material as well as differences between the different impression techniques. Initially 3 lb. was planned to be used to seat the trays to the standard position. Later on during the preliminary tests it was realized that the putty/light technique needed 28 lb. to reach the standard master model tray position. Different impression procedures needed different pressures to seat the tray into proper positions.

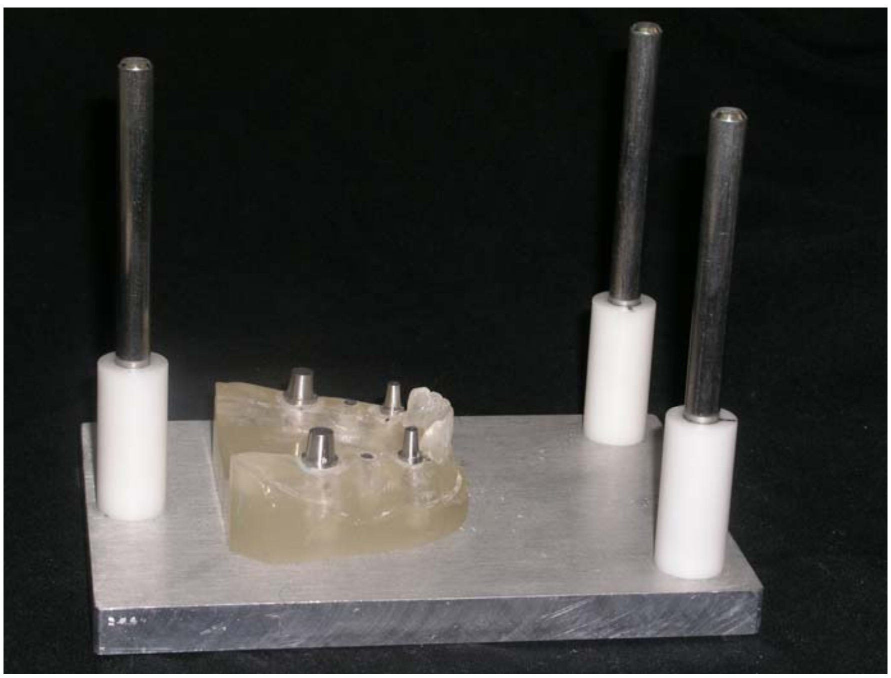

Figure 3-8. Master model attached to an aluminum plate. Note the three stainless steel guiding pins with the three plastic vertical stops

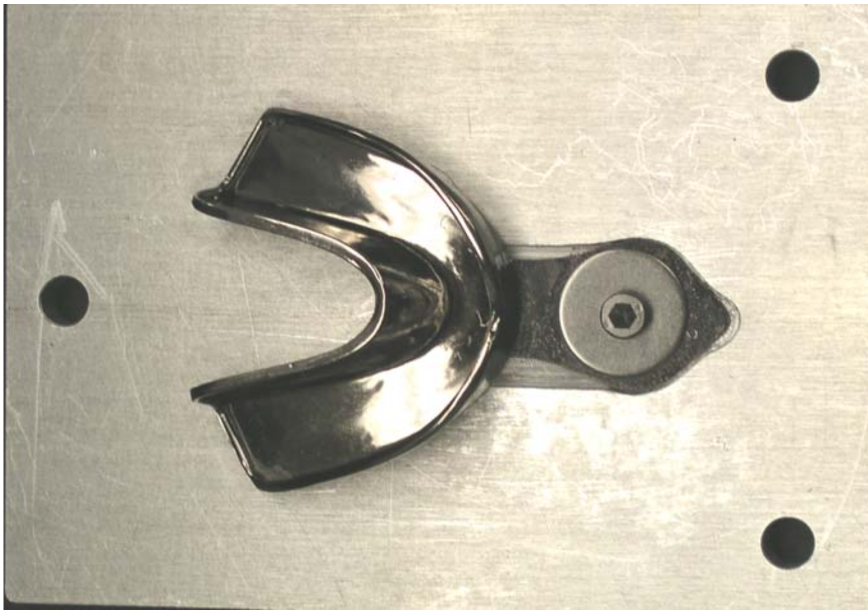

Figure 3-9. Metal tray secured to a second plate by a screw. Note the three holes that match the three guiding pin.

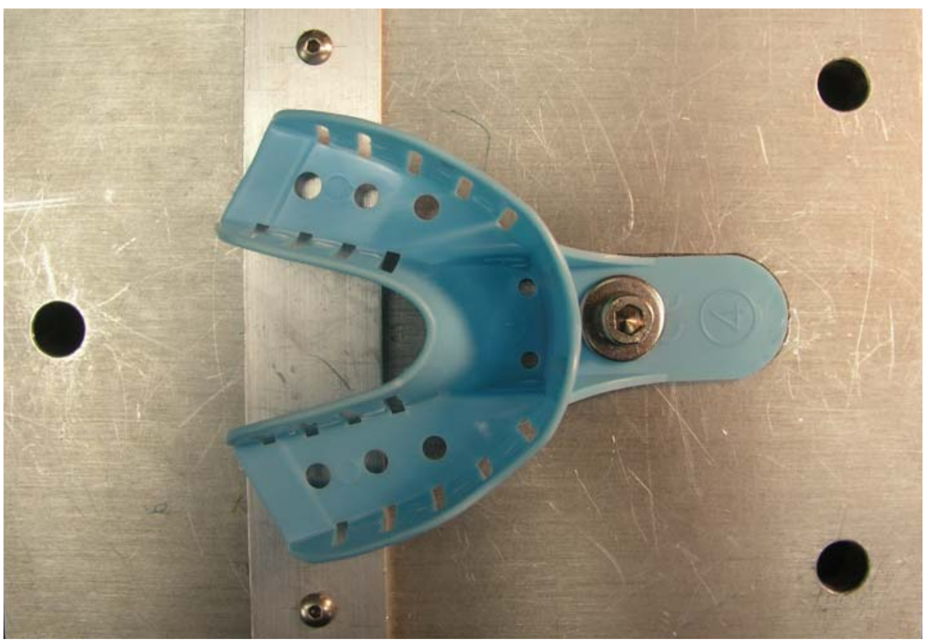

Figure 3-10. Plastic tray secured to a second plate by a screw. Note the three holes that match the three guiding pins. There is one plate design for plastic and another for metal.

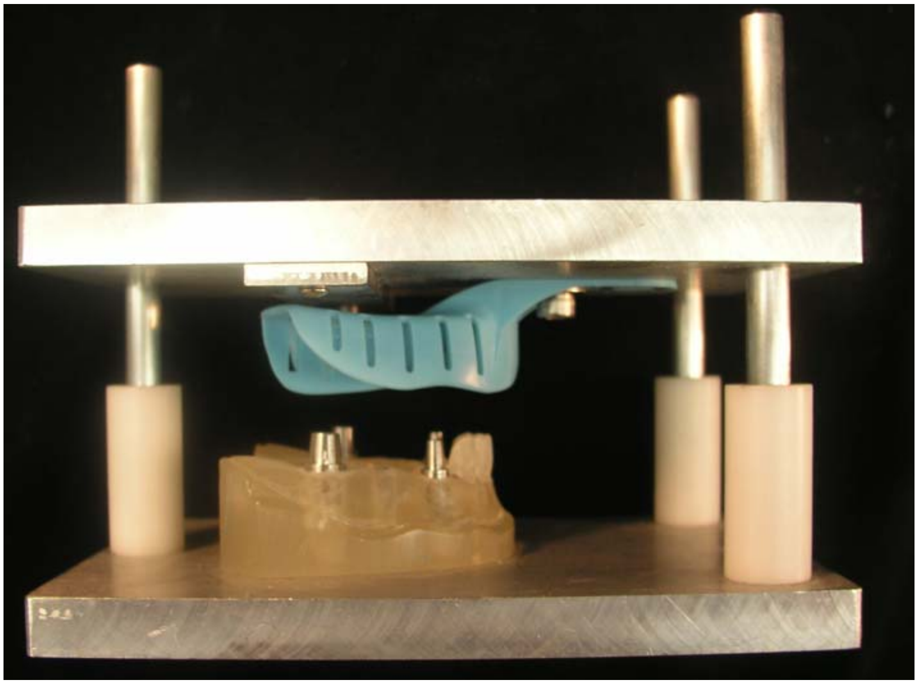

Figure 3-11. Lateral view of the two plates assembled previous to an impression procedure with the plastic tray

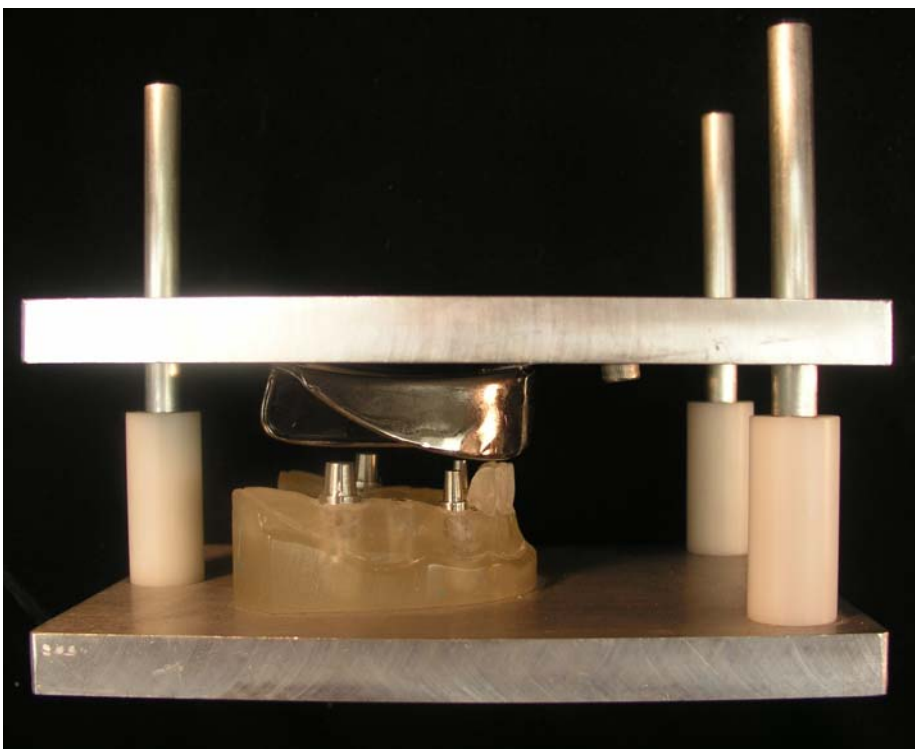

Figure 3-12. Lateral view of the two plates assembled previous to an impression procedure with the metal tray. Plastic stops for the metal tray are different in length from the ones for the plastic tray.

Heavy/Light Bodied Technique – Groups One and Four: The lower plate was prepared with the stops that matched the top plate (either plastic or metallic). The tray was screwed into place and checked against the master model for proper seating. Then the top plate was taken off, the tray was loaded with the heavy bodied consistency material and simultaneously the light bodied consistency material was injected directly onto the abutment replicas of tooth 44 and tooth 47. The top plate was placed and guided close to reach the stops and then a 3 lb weight was placed on top to fully seat the tray against the master model to the pre established ideal master /tray relation. This ideal master model/tray relation was built into the top plate design. When seating the top tray against the master model it was centered in close proximity to the model without touching it. After this procedure the impression was left undisturbed for 10 min and then removed in one quick pulling action. Last, the impression was inspected to verify that no bubbles were present on the marks.

Putty/ Light Bodied Without Spacer Technique – Groups Two and Five: The lower plate was prepared with the stops that matched the top plate (either plastic or metallic). The tray was screwed into place and checked against the master model for proper seating. Then the top plate was taken off, the tray was loaded with the putty material. The top plate was placed and guided close to reach the stops and then a 20 lb weight was placed on top to fully seat the tray against the master model to the pre established ideal master /tray relation. After this procedure the impression was left undisturbed for 6 min and then removed in one quick pulling action. Then the light material was injected around the abutments and inside the already set putty impression. The top plate was placed and guided close to reach the stops and then a 28 lb weight was placed on top to fully seat the tray against the master model to the pre established ideal master/tray relation. The impression was left undisturbed for 10 min and then removed in one quick pulling action. Last, the impression was inspected to verify that no bubbles were present on the marks.

Putty/ Light Bodied With Spacer Technique – Group Three and Six: The lower plate was prepared with the stops that matched the top plate (either plastic or metallic). The tray was screwed into place and checked against the master model with the 2 mm plastic spacer (Copyplast, Scheu Dental- Gmbh) in place for proper seating. Then the top plate was taken off, the tray was loaded with the putty material. The top plate was placed and guided close to reach the stops and then a 20 lb weight was placed on top to fully seat the tray against the master model to the pre established ideal master /tray relation. After this procedure the impression was left undisturbed for 6 min and then removed in one quick pulling action. The 2 mm plastic spacer was carefully retrieved from the putty and placed aside.

Then the light material was injected around the abutments and inside the already set putty impression. The top plate was placed and guided close to reach the stops and then a 3 lb weight was placed on top to fully seat the tray against the master model to the pre established ideal master /tray relation. The impression was left undisturbed for 10 min and then removed in one quick pulling action. Last, the impression was inspected to verify that no bubbles were present on the marks.

Measurements

Initially the coordinates (x, y and z) of the 11 marks on the master model were recorded. This coordinates were recorded 10 times on the master model for teeth 44 and 47 and for the reference rod using a measuring microscope (Figures 6 and 7) (Unitron

Universal Measuring Microscope, Unitron Instruments, Inc, Plainview, NY, USA). Same readings were made on impressions made no more than 24 h earlier. With the impressions attached to the table of the microscope, the coordinates for the eleven marks present on teeth 44 and 47, and the reference rod were recorded. Ten impressions per group were measured. Using the Pythagoras formula in three dimensions and the program Microsoft Excel (Microsoft Corporation) computer program the distances between the marks on the abutment replicas and the reference rod were calculated. The formula utilized to measure the distance between 2 points using the coordinates x, y and z was the following:

Distance from mark 1 to 6 = $\sqrt{(X_1 - X_6)^2 + (Y_1 - Y_6)^2 + (Z_1 - Z_6)^2}$

A total of 11 measurements per impression resulted from the computer calculation. Distance 1 is the distance between mark 1 on the master model and the reference mark which is mark 6. Distance 2 is the distance between mark 2 on the master model and the reference mark which is mark 6, and so on for every mark.

Statistical Evaluation

Six rounds of measurements of the 11 marks on teeth 44 and 47 and the reference mark on the stainless steel rod were done initially to determine the distances between the marks and the inherent errors associated with the measuring technique. Another 6 rounds of measurements were also done of a preliminary impression for similar purposes. Based on these results a statistical evaluation using a subunit of the SAS program (Statistical Program) mean values and standard deviations of master model and impression measurements were compared to determine the number of specimens needed to detect significant differences ($p<0.05$).

According to those calculations, a minimum of seven impressions per group would be needed to prove significant differences ($p<0.05$) between measurements on the master model and the studied impressions. Based on that finding, we decided to use 10 impressions per group. The coordinates of the eleven marks were recorded 10 times for the master model. The mean value for the different distances was calculated and used as the master model dimensions. The coordinates of the eleven marks on each impression were recorded once per impression, ten impressions per group. Comparisons between the different tray (stiffness) groups and impression thickness groups were conducted by use of a t-test and pair wise comparisons.

Figure 3-13. Lateral view of measuring microscope (Unitron Instruments, Inc)

Figure 3-14. Close up views of measuring microscope with master model in position for measurement and measuring devices on the instrument (silver knobs on the right image) (Unitron Instruments, Inc)

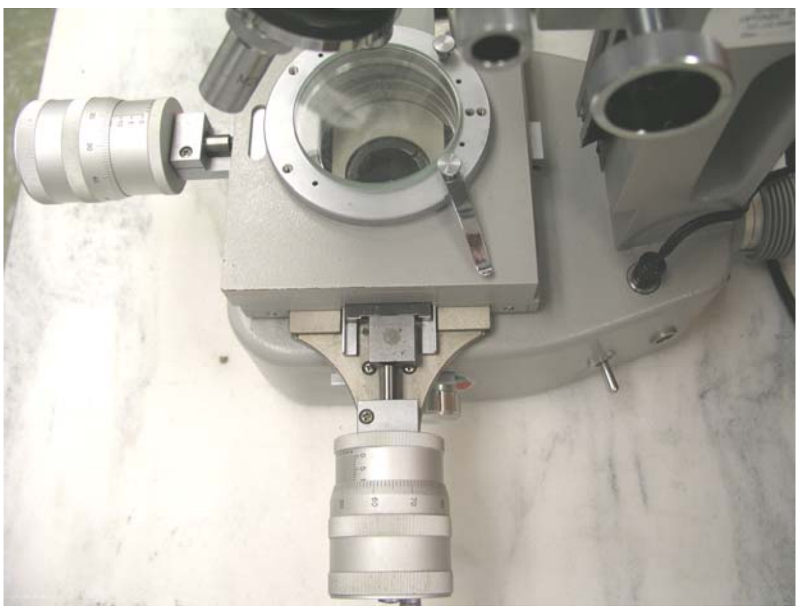

Figure 3-15. Close up views of measuring microscope with master model in position for measurement and measuring devices on the instrument (silver knobs on the right image)(Unitron Instruments, Inc)

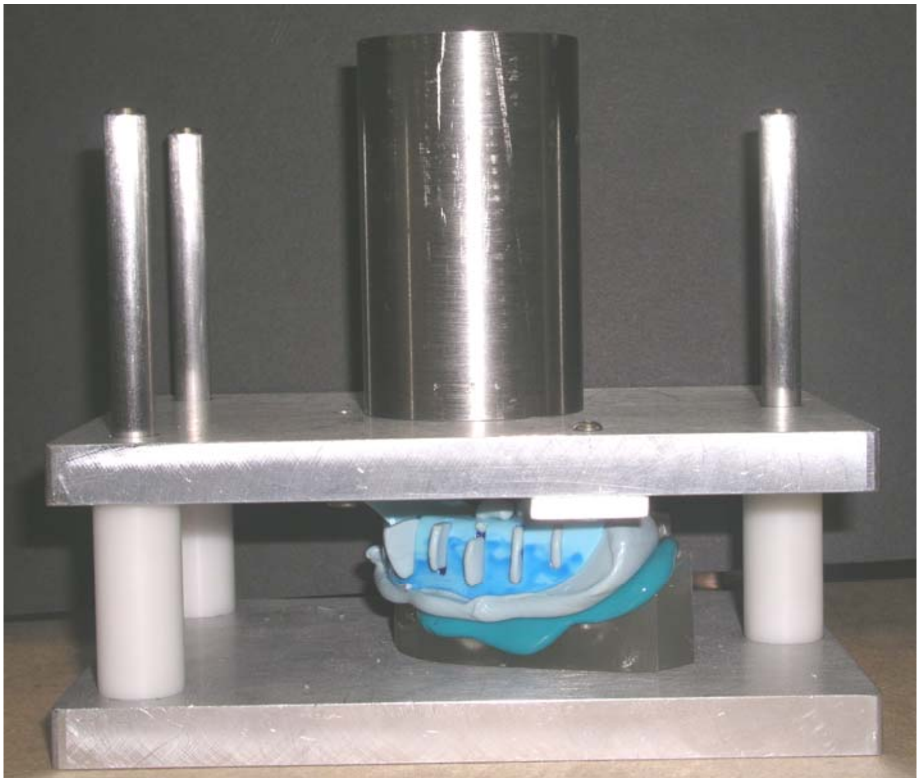

Figure 3-16. Lateral view of the impression device with the 3 pounds weight on top while taking one of the third group impressions

CHAPTER 4
RESULTS AND DISCUSSION

The results shown in Tables 4 -10 represent 11 distances expressed in microns between ten points on the abutments # 44 and # 47 and the reference point. Table 4 shows values for the master model. The reference point in Table 4 is represented by measurement 6 which is equal to 0 (compared to itself). Mean values, maximal values, standard deviations and minimal values are also shown in the tables. The distances between the different marks and the reference point were calculated and compared with the master model. The reference point was used in this study to be able to identify changes in space of each abutment.

Using a t-test and pair wise comparisons, significant differences ($p<0.05$) were found between four of the investigated groups and the master model. All techniques (PL, SP and HL) used with the plastic trays had distances that were significantly different from the master model, while for the metal trays it was only the HL technique that resulted in a distance that was significantly shorter than the matching distance on the master model.

Groups 2 and 3 used plastic tray /putty/light (PPL) and plastic tray/putty/light with spacer (PSP) respectively, and were the two groups that had the largest number of distances which were significantly different from the master model. For group 2 (PPL), the distances numbered 3, 4, 8 and 10 had values that differed with the master model ranging from 94.2 μm on distance 4 to 161.8 μm on distance 10. For group 3 (PSP), distances 1, 3, and 8 differed from the master model with a difference ranging from 75.8

µm to 106.2 µm. Distortion found on groups 2 (PPL) and 3 (PSP) may be attributed to tray distortion.

Group 1 consisting of plastic tray/heavy-light material (PHL) and group 4 consisting of metallic tray/heavy-light material (MHL) respectively also presented significant differences in one of the 10 distances. Group 1 (PHL) was significantly different in distance 5 with 72.6 µm and group 4 (MHL) in distance 2 with 61.4 µm. Changes in groups 1 (PHL) and 4 (MHL) may be related to material bulk and polymerization shrinkage. The discrepancies found on these two groups are probably still clinically acceptable for certain procedures. Differences in distances up to 90 µm between abutments for a fixed partial denture have been estimated as acceptable (46) due to the fact that the periodontal ligament measures from 100 µm to 250 µm (57). Probably even higher values than 90 µm are acceptable for some patients. It means that perhaps under pressure the bridge fabricated from a slightly differently sized cast could seat onto the abutments and fit properly against them. This amount of distortion for a multiple implant bridge/structure would have a different outcome; it would probably be clinically unacceptable because its inability to adapt to the stiff implants. Vigolo *et al.* in their study about impression techniques for multiple implant found that discrepancies up to 34 µm were judged as acceptable and “passive” to manual and visual inspection (53). Fortunately, such big variations in length are found only when dealing with edentulous spans where the impression material bulk is big and is highly susceptible to polymerization shrinkage and thermal changes. Intra abutment dimensions are not affected enough by all impression variables to make them clinically important. It has been recognized in the past that dimensional changes in intra abutment dimensions are very minimal when a-silicone or polyether is used in conjunction with stock or custom trays (40, 45, and 49). Ultimately, the main goal is to have a restorative margin sealed either for a single crown or for a multiple unit fixed partial denture.

The rigidity of the tray is one of the multiple factors related to impression accuracy (13). Great distortions of trays have been shown in a study when comparing plastic stock trays with metal trays while performing impressions with putty material. (10). Plastic tray flexibility was probably the cause for the distortion seen for groups 2 (PPL) and 3 (PSP) where the pressure created by the putty could have distorted initially the trays and then the pressure of the light material during the second impression stage increased the distortion even more. Rigid trays have been recommended by some authors (13, 9) in order to reduce distortion during seating and removal of the trays from the patient's mouth. Gordon *et al.* found up to 100 µm difference on inter abutment distances and 260 µm cross arch discrepancy when using plastic stock trays. They attributed this distortion to tray flexibility. Comparable distortion was found in this study with the plastic trays when using an impression technique with putty material (19).

It is almost impossible to simulate and analyze all the variables affecting such a complex event as the impression procedure is. The complexity of impression making probably goes even further than one could possibly imagine. Local anesthetics and the time at which the impressions are made have been shown to have the most significant impact on the final clinical outcome (54). Further more, materials which do not perform well in laboratory studies do sometimes very well in clinical studies (54). In our study many variables such as tray rigidity (stock plastic or stock metal), material bulkiness, type of impression material, tray adhesion, tray seating pressure, pouring time and impression technique were considered. Other variables were purposely not considered in order to isolate and simplify the studied variables. Some of the variables not considered were: use of custom tray, mouth temperature, moisture, undercuts, other impression materials, cast production, and castings just to name some of them.

In our study, the master model was designed in line with what has been done in previous studies (Tables 2.1 to 2.4). Six degree taper stainless steel abutments for a 4 unit fixed partial denture. The reviewed studies have used from parallel walls up to 12° taper, which probably is closer to reality. The base of the model was fabricated in plastic due to the fact that this study did not simulate oral temperature. Therefore a more stable model base such as metal was not needed. Some studies may have incorporated this potential source of error inadvertently (39). Pins to standardize tray seating are very popular among these in vitro studies (43, 52). Seating pressure is not commonly standardized, but it seems to have some influence on material behavior (54). No studies were found on this specific topic. In previous studies, weights as well as universal testing machines have been used to standardize the forces while seating the tray against the master model time after time (43, 52). Interestingly enough, the forces used in a previous study with an Instron testing machine closely resemble the ones used in our study (52). The differences in weights used for the different techniques were due to the fact that different techniques, materials and trays required different levels of pressure to establish ideal master /tray relationship. As an interesting observation, the metal trays, when loaded with the putty for the first step impression (putty groups) always took little longer time to reach the stops. Plastic trays, probably due to their higher flexibility, did not show this behavior confirming the results by Cho *et al.* (10) regarding tray distortion. This behavior resembles what happens clinically when we need to apply different pressures while using different impression material viscosities. The top plates used to attach the trays (one for plastic and one for metal trays) weighted 2 lb each. This weight was not incorporated in the description of the different techniques. It is important to mention that these 2 lb were not included when we discuss tray loads. In other words, the total tray load is 2 lb higher than listed.

This study measured the distances directly on the impressions and not on stone models like many others have done (14, 15, 27, 37, and 43). First, by measuring the impressions, errors incorporated during gypsum pouring could be avoided. Second, before this study was conducted, an impression was made of the master model using an a-silicone H/L technique. The impression was then poured with type IV stone and evaluated under the microscope. The marks created with a diamond bur on the stainless steel abutments of the master model were very easy to read on the impression under the microscope, but the same marks were blurred and poorly defined in the stone cast. For those reasons, stone casts measurements were not incorporated in this study. Stone casts and metal castings resemble closely what happens in the dental laboratory, but such an evaluation would introduce many more variables and sources of errors, making it even more difficult to identify the real influence of the variables being studied.

It is also known that temperature changes have great influence on impression materials and their accuracy (16). After 5 minutes in the mouth an impression can reach 33°C (23). When retrieved from the mouth, the room temperature is about 23°C. That is a 10°C drop in temperature. Furthermore, when poured, the water temperature is even lower and may also influence the thermal contraction of the impression. Impression temperature changes from the mouth (37°C) to room temperature (23°C) was found in one study to be the dominating factor in die inaccuracy (16).

Undercut is another variable that was not included in this study. Its importance regarding impression accuracy is well recognized (12). The greater the undercut is, the more likely a thin layer of impression material will deform permanently. On the other hand, the thicker the material layer is, the more susceptible it becomes to polymerization shrinkage. Thin layers of 2-3 mm of impression material are accepted to produce accurate dies even in the presence of undercuts (21, 22, and 24).

The instrument used for the measurements is a Unitron Microscope capable of measuring down to 1 μm. Coordinates were recorded for each of the eleven marks on abutment 44, abutment 47, and reference point. Later the coordinates were used to calculate distances in the computer. Coordinates x and y were very easy to read in a very precise manner. The z coordinate, which was recorded with the lens scale, was much more cumbersome to determine and therefore less precise and less reproducible. Therefore, the accuracy for the z coordinate is much lower than for the other two.

A major limitation with our study is that we did not consider intra abutment measurements. It has been expressed theoretically that bucco-lingual dimensions of dies produced from distorted putty impressions from tray recoil are much smaller, producing oval shape dies rather than of round ones (9). However, it was very unlikely that we could have detected any significant difference measuring the impressions directly.

One study reported better fitting of the resulting castings on the master model when metal or rigid plastic trays were used (9).

Table 4-1 Mean and standard deviation of ten rounds of measurements performed on the eleven marks of the Master model

Distance #	n	Mean (µm)	S.D. (µm)	Minimum (µm)	Maximum (µm)
1	10	18071.5	27.9	18032.4	18121.8
2	10	14899.0	32.5	14846.2	14948.7
3	10	15577.4	26.3	15538.3	15613.6
4	10	9186.0	46.7	9087.3	9251.2
5	10	17665.2	70.1	17567.9	17789.3
6	10	0	0	0	0
7	10	9994.1	26.1	9959.0	10036.5
8	10	14336.6	25.3	14313.2	14390.0
9	10	12629.7	35.5	12594.5	12708.0
10	10	15721.6	18.9	15694.6	15765.6
11	10	14758.2	58.3	14655.2	14861.1

D = Distance measured
n = Number of measurements of the same distance in the master model.
S.D. = Standard deviation

Table 4.2 Measurements from ten impressions taken with a plastic tray and the heavy/light bodied technique (Group 1)

Distance #	n	Mean (µm)	S.D. (µm)	Minimum (µm)	Maximum (µm)
1	10	18062.1	24.3	18033.8	18104.1
2	10	14888.0	37.2	14835.4	14961.7
3	10	15579.5	25.0	15543.3	15625.8
4	10	9190.4	61.2	9124.2	9306.4
5	10	17592.6	63.5	17510.0	17738.2
6	10	0	0	0	0
7	10	9984.1	27.1	9943.3	10049.2
8	10	14302.7	29.2	14269.5	14352.9
9	10	12605.8	25.4	12575.7	12657.5
10	10	15737.9	36.6	15694.6	15822.4
11	10	14722.7	299.4	13903.0	14954.4

D = Distance measured
n = Number of measurements of the same distance in the master model.
S.D. = Standard deviation

Table 4-3 Measurements from ten impressions taken with a plastic tray and the putty/light bodied without spacer technique (Group 2)

Distance #	n	Mean (μm)	S.D. (μm)	Minimum (μm)	Maximum (μm)
1	10	18043.3	128.3	17856.0	18353.9
2	10	14917.4	83.1	14855.6	15133.5
3	10	15476.4	102.2	15364.6	15737.5
4	10	9280.1	77.6	9217.1	9477.2
5	10	17623.7	126.7	17458.6	17888.1
6	10	0	0	0	0
7	10	10189.4	587.0	9775.7	11831.8
8	10	14194.4	89.5	13975.2	14264.0
9	10	12686.5	57.2	12613.6	12828.5
10	10	15559.8	299.5	147514.6	15749.9
11	10	14783.8	116.4	14492.1	14914.9

D = Distance measured
n = Number of measurements of the same distance in the master model.
S.D. = Standard deviation

Table 4-4 Measurements from ten impressions taken with a plastic tray and the putty/light bodied with spacer technique (Group 3)

Distance #	n	Mean (μm)	S.D. (μm)	Minimum (μm)	Maximum (μm)
1	10	17995.7	26.0	17955.6	18031.2
2	10	14896.5	61.0	14808.0	15025.6
3	10	15473.4	78.3	15288.1	15564.0
4	10	9163.2	45.3	9081.1	9212.8
5	10	17594.5	72.8	17475.1	17702.8
6	10	0	0	0	0
7	10	9998.4	85.6	9900.9	10217.7
8	10	14239.8	64.0	14109.6	14343.6
9	10	12627.4	23.6	12596.8	12677.3
10	10	15658.2	84.5	15447.4	15779.4
11	10	14772.1	55.8	14701.8	14912.0

D = Distance measured
n = Number of measurements of the same distance in the master model.
S.D. = Standard deviation

Table 4-5 Measurements from ten impressions taken with a metal tray and the heavy/light bodied technique (Group 4)

Distance #	n	Mean (µm)	S.D. (µm)	Minimum (µm)	Maximum (µm)
1	10	18066.3	17.6	18029.6	18089.8
2	10	14837.7	81.4	14617.0	14898.1
3	10	15631.9	103.1	15580.6	15924.2
4	10	9164.7	24.9	9132.8	9209.7
5	10	17658.7	69.9	17542.8	17739.3
6	10	0	0	0	0
7	10	9997.0	18.5	9979.9	10044.8
8	10	14335.4	49.3	14197.5	14370.0
9	10	12802.5	504.7	12600.4	14221.4
10	10	15761.7	45.9	15730.8	15858.8
11	10	14806.3	65.1	14699.3	14916.9

D = Distance measured
n = Number of measurements of the same distance in the master model.
S.D. = Standard deviation

Table 4-6 Measurements from ten impressions taken with a metal tray and the putty/light bodied without spacer technique (Group 5)

Distance #	n	Mean (µm)	S.D. (µm)	Minimum (µm)	Maximum (µm)
1	10	18054.3	15.1	18032.1	18079.8
2	10	14854.1	22.2	14829.6	14900.0
3	10	15579.7	19.2	15553.0	15615.0
4	10	9211.1	17.2	9186.3	9235.4
5	10	17667.0	68.4	17544.6	17744.7
6	10	0	0	0	0
7	10	9939.0	312.5	9050.8	10078.2
8	10	14356.3	19.1	14317.0	14386.6
9	10	12711.1	114.5	12627.0	12883.7
10	10	15783.0	19.6	15755.7	15808.2
11	10	14832.5	80.1	14685.5	14934.9

D = Distance measured
n = Number of measurements of the same distance in the master model.
S.D. = Standard deviation

Table 4-7 Measurements from ten impressions taken with a metal tray and the putty/light bodied with spacer technique (Group 6)

Distance #	n	Mean (µm)	S.D. (µm)	Minimum (µm)	Maximum (µm)
1	10	18047.1	19.8	18018.9	18073.6
2	10	14886.0	24.6	14858.7	14931.1
3	10	15568.6	29.0	15525.0	15611.7
4	10	9176.4	28.6	9136.9	9218.4
5	10	17675.0	75.9	17538.7	17745.0
6	10	0	0	0	0
7	10	9991.6	20.2	9950.8	10022.9
8	10	14329.1	20.3	14291.1	14354.2
9	10	12618.1	19.4	12584.5	12654.4
10	10	15730.1	24.8	15696.0	15777.0
11	10	14800.0	69.6	14677.9	14917.2

D = Distance measured
n = Number of measurements of the same distance in the master model.
S.D. = Standard deviation

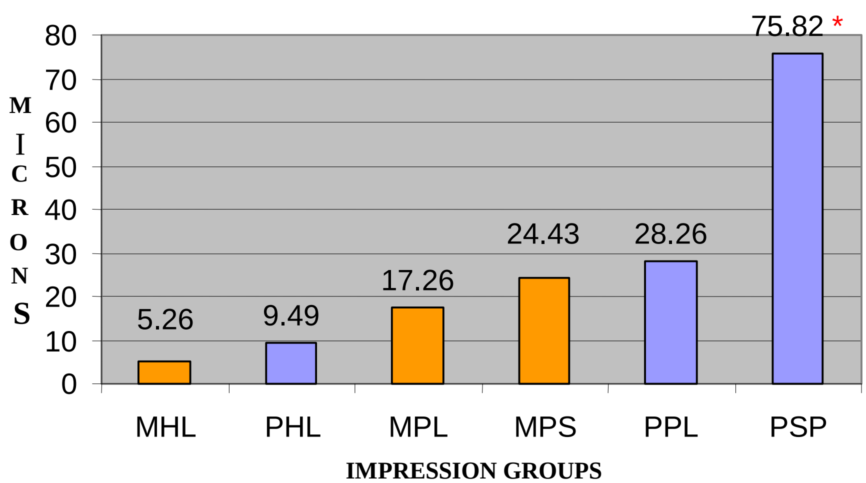

Figure 4-1. Difference between master model and impression groups in distance 1.

Significantly different values marked with a red star. Plastic tray groups in blue and metal tray groups in orange.

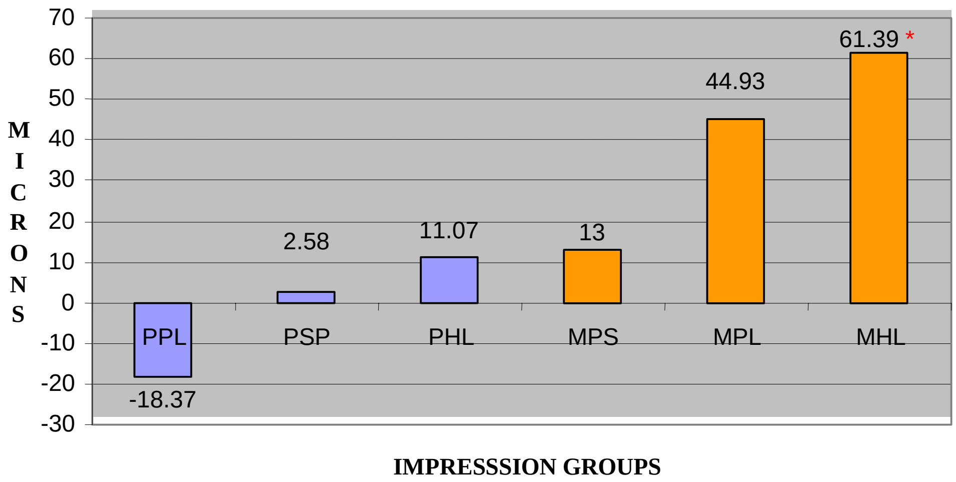

Figure 4-2. Difference between master model and impression groups in distance 2

Significantly different values marked with a red star. Plastic tray groups in blue and metal tray groups in orange

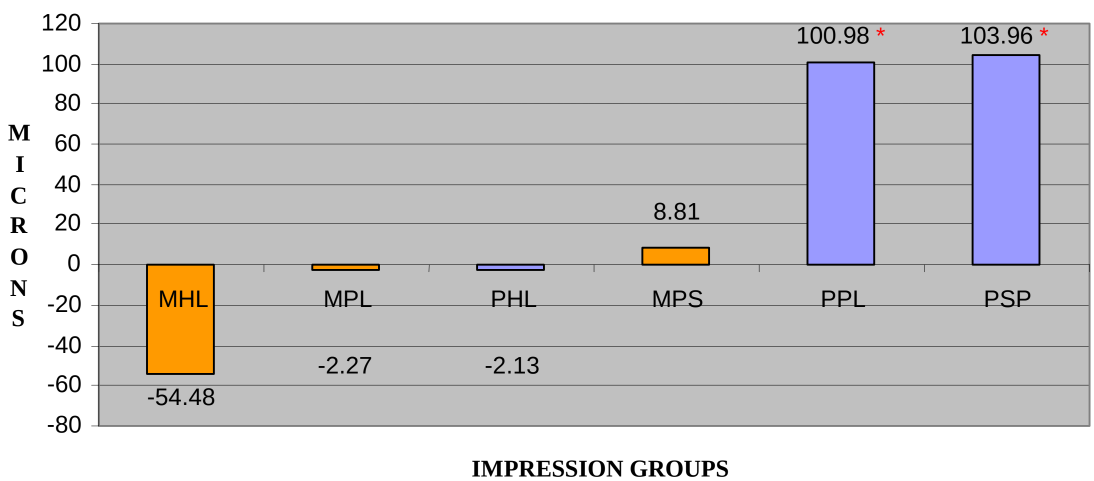

Figure 4-3. Difference between master model and impression groups in distance 3.

Significantly different values marked with a red star. Plastic tray groups in blue and metal tray groups in orange

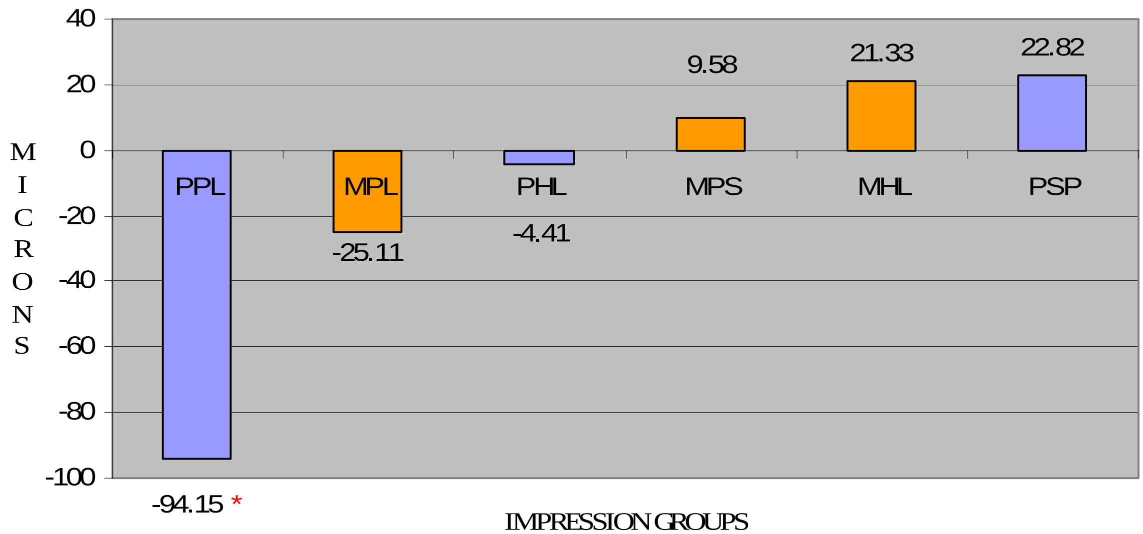

Figure 4-4. Difference between master model and impression groups in distance 4.

Significantly different values marked with a red star. Plastic tray groups in blue and metal tray groups in orange

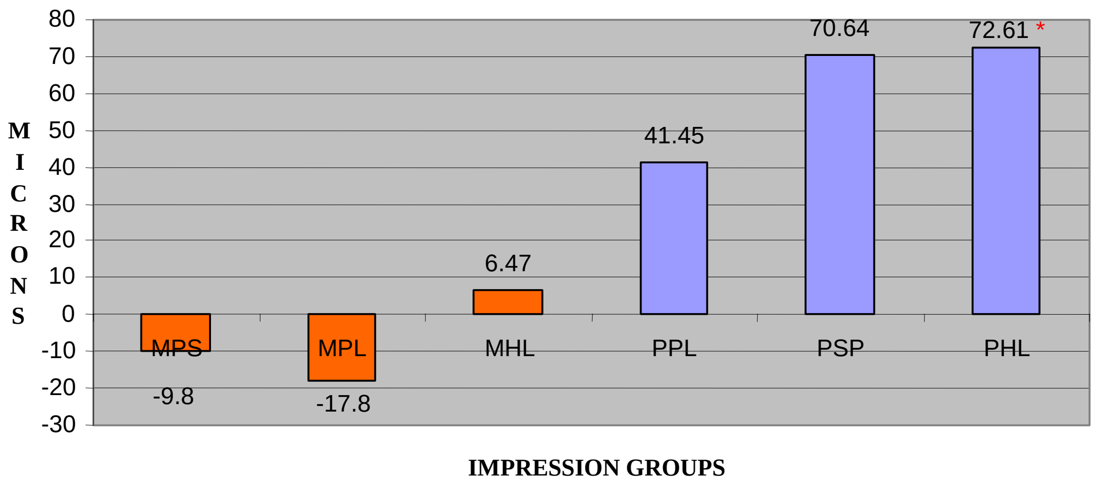

Figure 4-5. Difference between master model and impression groups in distance 5.

Significantly different values marked with a red star. Plastic tray groups in blue and metal tray groups in orange

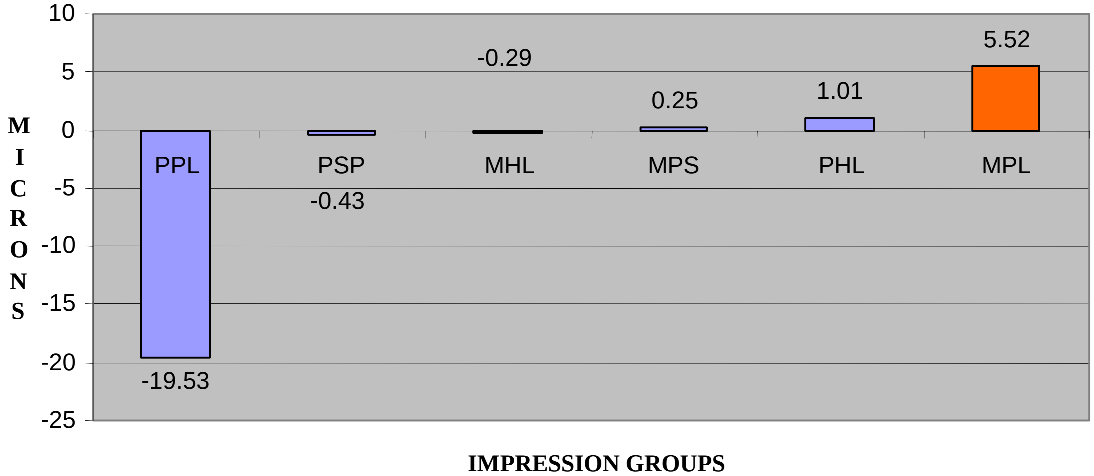

Figure 4-6. Difference between master model and impression groups in distance 7.

Significantly different values marked with a red star. Plastic tray groups in blue and metal tray groups in orange

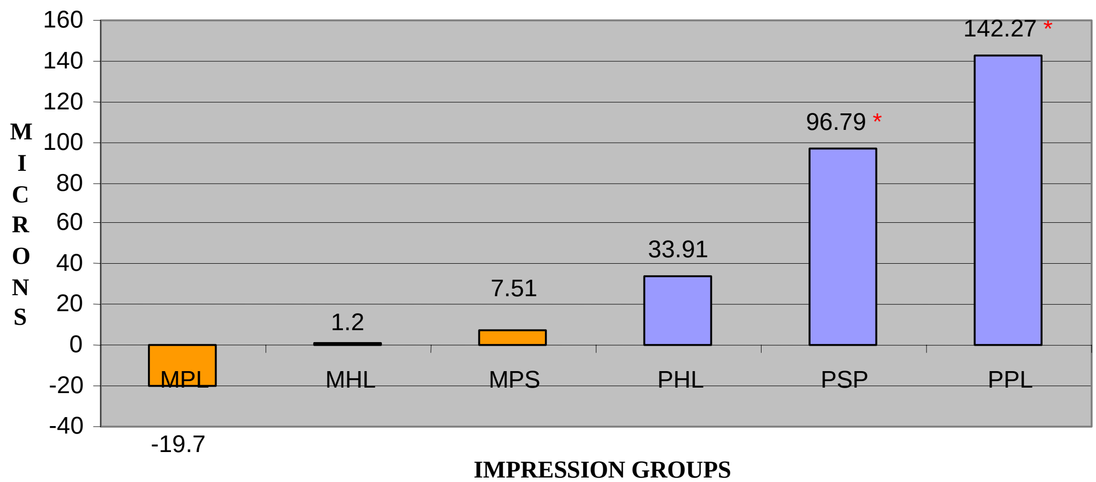

Figure 4-7. Difference between master model and impression groups in distance 8.

Significantly different values marked with a red star. Plastic tray groups in blue and metal tray groups in orange

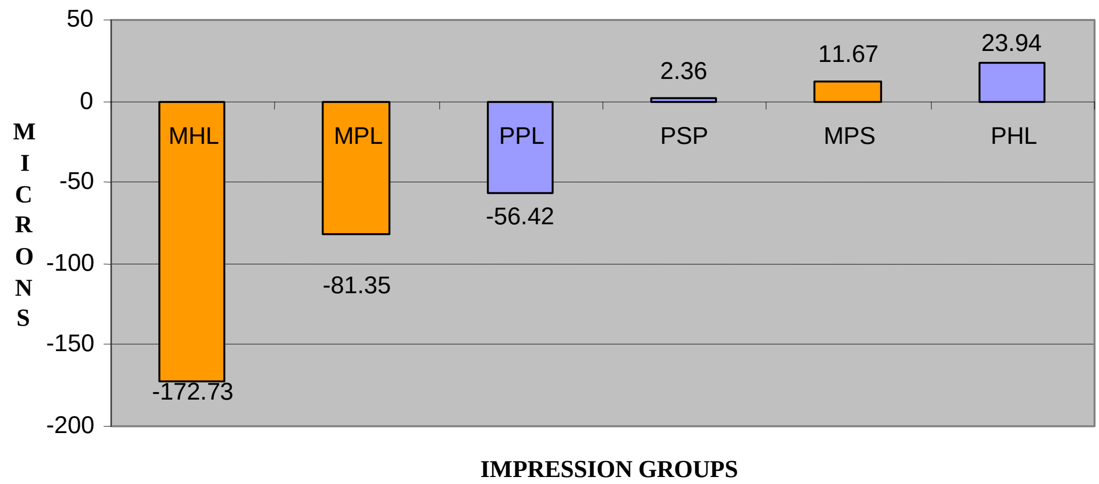

Figure 4-8. Difference between master model and impression groups in distance 9.

Significantly different values marked with a red star. Plastic tray groups in blue and metal tray groups in orange

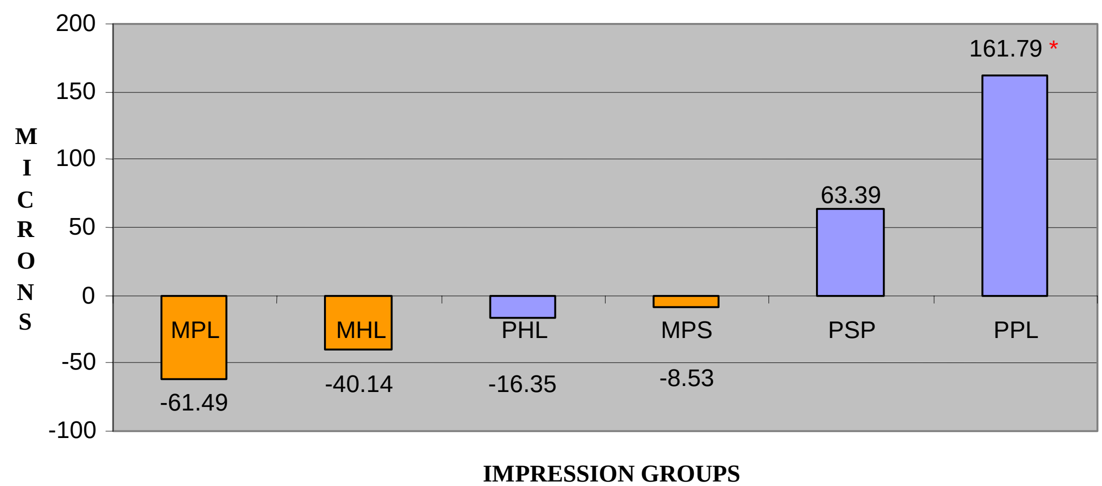

Figure 4-9. Difference between master model and impression groups in distance 10.

Significantly different values marked with a red star. Plastic tray groups in blue and metal tray groups in orange

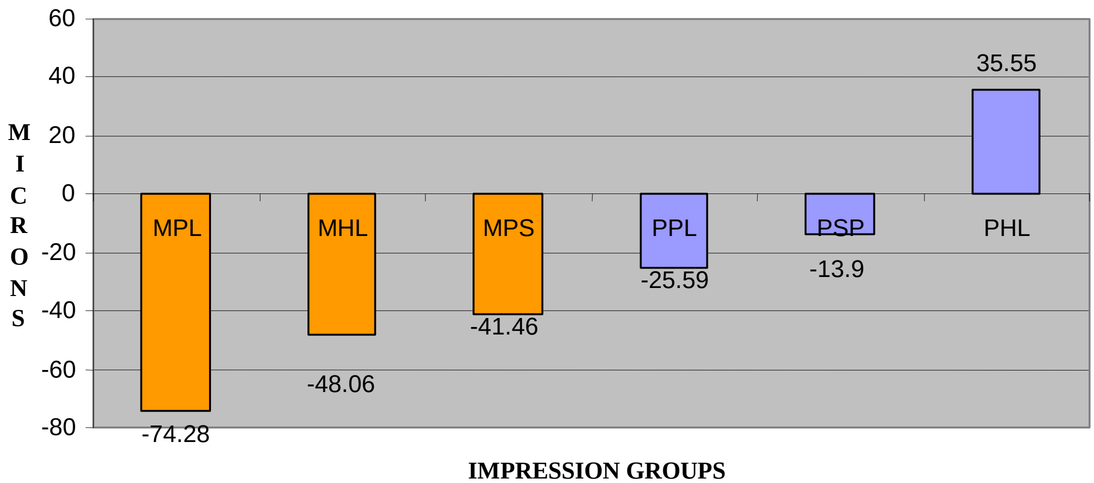

Figure 4-10. Difference between master model and impression groups in distance 11. Significantly different values marked with a red star. Plastic tray groups in blue and metal tray groups in orange

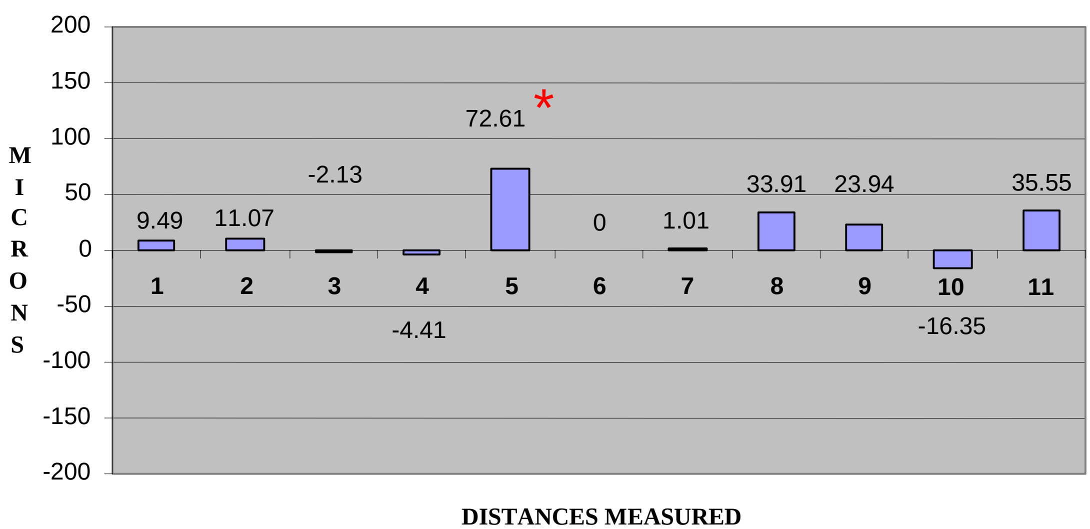

Figure 4-11. All distances mean difference value for group 1 (PHL) in comparison to master model.

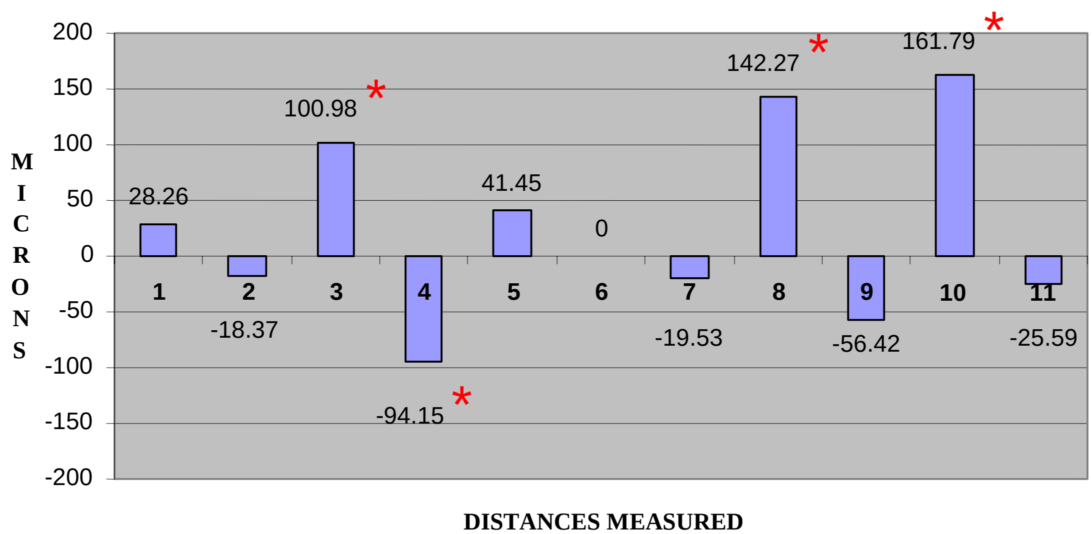

Figure 4-12. All distances mean difference value for group 2 (PPL) in comparison to master model.

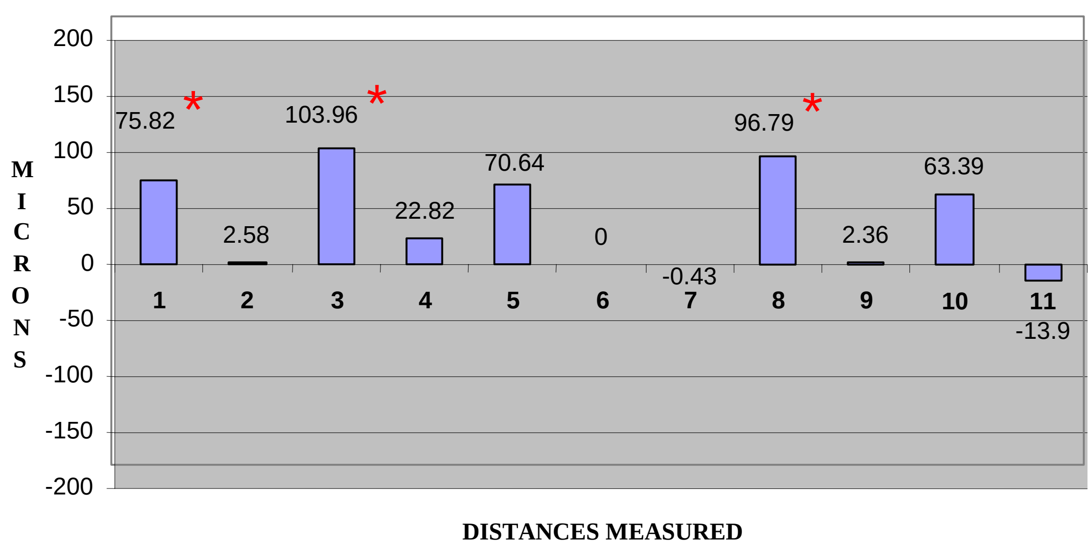

Figure 4-13. All distances mean difference value for group 3 (PSP) in comparison to master model.

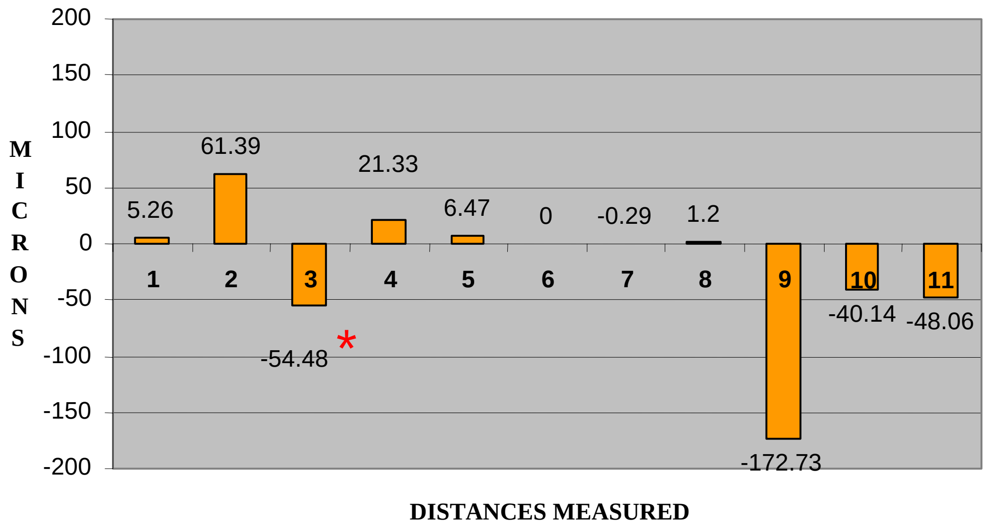

Figure 4-14. All distances mean difference value for group 4 (MHL) in comparison to master model.

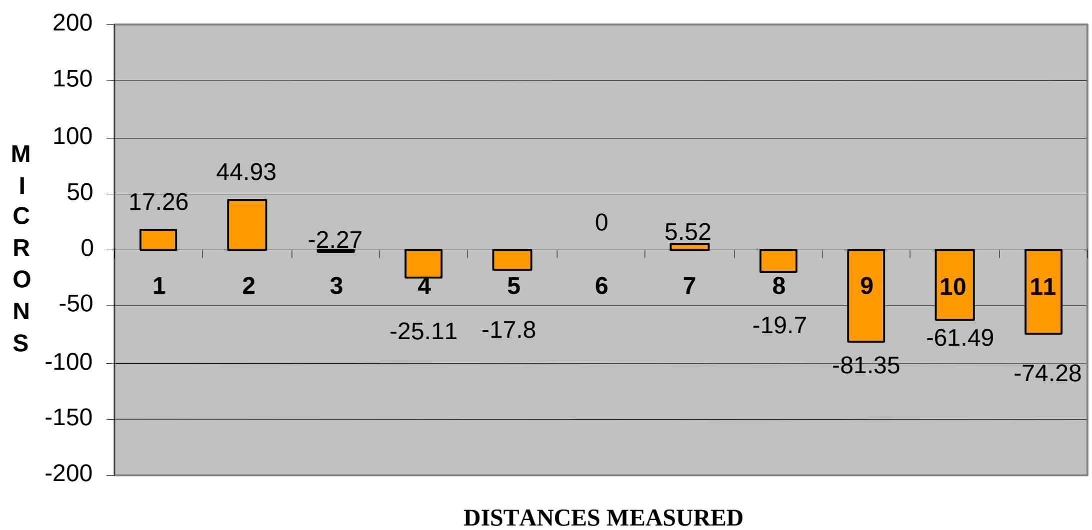

Figure 4-15. All distances mean difference value for group 5 (MPL) in comparison to master model.

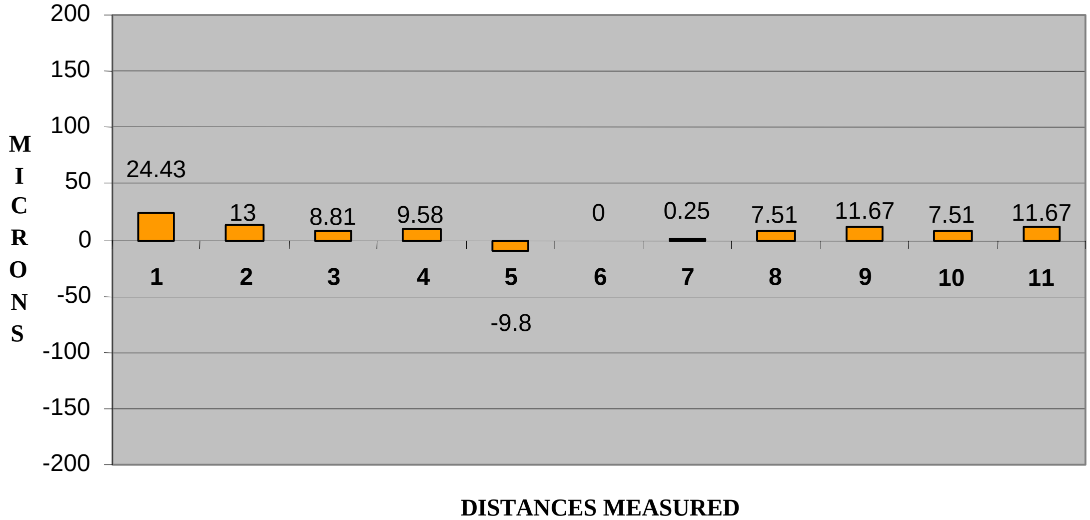

Figure 4-16. All distances mean difference value for group 6 (MSP) in comparison to master model.

CHAPTER 5
SUMMARY AND CONCLUSIONS

Plastic trays produced less accurate impressions than metal trays. When metal trays were used, putty based impressions were dimensionally better than heavy/light body impressions. Consequently, tray rigidity and material bulk control through the use of two stage techniques improved impression reliability.

Future work can be done as described here. As shown in other studies (9, 13, 14, and 34), this study supported claims that factors such as the control of the impression material thickness and the tray rigidity affect the impression accuracy. Custom trays have been the gold standard for many years because they control the thickness, but little attention has been paid to the rigidity required by them to perform well during impression procedures. In a future project it would be interesting to test under the same conditions described in this study the performance of custom trays against the Rim-Lock metal tray using putty viscosity technique in two steps with the metal trays. It would also be interesting to include as impression technique in a new project the putty/light one step impression technique. This technique has been criticized in the past because supposedly some of the margins are imprinted in putty material which does not fulfill the specifications for detail reproduction. Is it truly putty against the margin or a few microns layer of light body material that cannot be seen by the human eye? The reason for that critique has never been supported by reliable research evidences.

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BIOGRAPHICAL SKETCH

I got my dental diploma from the "Instituto de Ciencias de la Salud CES" in Medellin, Colombia, South America, in December of 1995. My undergraduate thesis was "Craniofacial and Dentoalveolar Changes with First Permanent Molars Extraction" which was part of a large longitudinal study in growth and development. In 1997 I enrolled in a two and a half year specialty program in periodontal-prosthesis at the same university. I became a specialist in April 2000. My thesis project "SAMM-III. Analysis and Design of a Mandibular Movement Measurement System" was named as the Best Dental Postgraduate Research Work 2000. After living in Colombia since age 4, I decided in 2000 to come back to the United States fleeing from the violence in this country. From 2001 to 2003, I did the Foreign Trained Dentist (FTD) program at University of Florida, obtaining the Florida dental license the same year. In 2003, I started a three year specialty program in prosthodontics with a Master of Science at the University of Florida. I received my Master of Science in prosthodontics in May 2006. Currently, I am planning to establish my dental practice in Ocala, Florida, limited to prosthodontics. I am also planning to serve as a visiting faculty in the graduate prosthodontics program at University of Florida. My wife Paula has been my support and engine throughout all these years at school. After completion of my specialty a new era starts in our lives.