A COMPARISON OF THE ACCURACY OF POLYETHER, POLYVINYL SILOXANE, AND PLASTER IMPRESSION FOR LONG-SPAN IMPLANT SUPPORTED PROSTHESES

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A research report submitted for partial completion of Masters in Dentistry in Prosthodontics

Declaration

I, VYONNE JACQUELINE HOODS-MOONSAMMY declare that this research report is my own work. It is being submitted for the degree of Master of Dentistry in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at this or any other University.

Signed …………………………………………

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Dedication

I dedicate this research report to my family, Gary, Chanel and Miche, for their continued love and support.

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Abstract

Purpose

It is known that distortions can occur during impression making and the pouring of casts, and that this distortion may produce inaccuracies of subsequent castings, especially long span castings for implant superstructures. The purpose of this study was to compare the ability of different impression materials to reproduce the positions of 5 implant analogues on a master model, in terms of their accuracy and the accuracy of a resultant cast, relative to the master model.

Method

The master model was a stainless steel model with 5 implant analogues. The impression materials used were impression plaster (Plastogum), a polyether (Impregum Penta), and two polyvinyl siloxane materials (Aquasil Monophase and Aquasil putty with light body wash). Five impressions were made with each impression material and cast in Satin stone under controlled conditions. The positions of the implants on the master model, the impression copings, and the implant analogues in the subsequent cast were measured using a co-ordinate measuring machine which measures within 4μm of accuracy.

Results

Statistical analysis using a one factor t-test indicated that distortion occurred in all the impression materials, but inconsistently. Aquasil Monophase reproduced the master model most accurately. Although there was no significant distortion between the Aquasil monophase impressions and the master model or between the impressions and their casts, there were distortions between the master model and the master cast,

which highlighted the cumulative effects of the distortions. Impregum’s performance proved to be the most reliable in terms of predictability. Plastogum displayed cumulative distortion and with Aquasil putty with light body, these impression materials had the least reliability.

Conclusions

Some of the distortions observed are of clinical significance and likely to contribute to a lack of passive fit of any superstructure. The unpredictability of such distortions may mean that the future of accurate impressions and superstructures may lie in the digital world.

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1 Introduction

The use of dental endosseous implants to replace missing teeth in partially dentate and edentulous patients is associated with a high success rate from an aesthetic, functional, and psychological point of view. However, biomechanical failure does occur in long span prostheses. The mechanical aspect of failure is likely to be due to lack of a passive fit of the implant superstructure.

In a review of the literature by Wee, Aquilino and Schneider (1999) it was concluded that multiple factors may prevent a passive fit despite accurate implant prosthodontic procedures. Accuracy of all the steps from the impression to the final casting is required but the procedures and materials explored have shown that achieving a precise fit on the implant prosthesis may not be possible. The impression is the initial step in such procedures where inaccuracies could be introduced. Ultimately the resultant inaccuracy of the fit of the implant superstructure to the implants is thought to introduce significant force on the implants and their connected fixed prosthesis (Jemt, 1991).

The existing forces inherent in the tightened superstructure are of static and dynamic nature. The consequences of dynamic forces (tensile and compressive, functional and parafunctional) existing in the presence of static forces (due to inaccuracy when an ill-fitting framework is connected) may manifest early or late, as they remain for years after prosthesis placement (Jemt and Lekholm, 1998). Because the implants are ankylotic, do not yield, and are connected to a rigid superstructure, the stresses are transferred to the entire assembly with all its components. This may lead to implant failure or metal fatigue fractures. Zarb and Schmitt (1990) also ascribed loosening or fractures of screws in part to an ill-fitting superstructure in addition to clinical stress loading (function and parafunction).

While failure is uncommon, its management is very costly from a biological, time, convenience and economic perspective in terms of maintenance or replacement. The accuracy of the steps required from impression to the final casting contributes to achieving a passive fit of the resultant superstructure which would lessen the inherent stresses. A misfit of 150μm is widely regarded to be the upper limit of clinical acceptability (Jemt, 1991). The search for the best impression technique and material that is associated with the least amount of error is an important first step towards achieving this goal.

Previous comparative analyses of the dimensional accuracy of various impression materials will serve as an addition to existing evidence, and provide new information in that some of the impression materials have been improved or modified.

This current study will be an in vitro comparative analysis to compare the accuracy of polyether (Impregum Penta ®, Pentamix, 3M ESPE, AG Seefeld, Germany), a polyvinyl siloxane (PVS) monophase (Aquasil Ultra DECA Monophase, Dentsply Friadent, Konstanz, Germany), a PVS putty and light-body wash combination (Aquasil Putty Deca and Ultra LV Regular Set),) to a control of impression plaster (Plastogum ® Harry J. Bosworth, Skokie, Illinois). The study will also evaluate dimensional accuracy with respect to viscosity of the material: monophase / single viscosity materials with the putty and wash (dual phase) technique. The null hypothesis is that there would be no difference in the three-dimensional accuracy between the impression materials under investigation. Distortion would be evaluated within the dental arch and between abutments.

2 Literature Review

The dimensional accuracy and detailed reproduction of an impression material is a pre-requisite for fulfilling its role in transferring information from the patient to the dental laboratory. The impression technique, impression tray, and properties of the impression material all contribute to the accuracy of the impression (Luthardt et al, 2008).

The literature has documented the accuracy of the various impression materials in search of the ‘ideal’ one that is associated with the least degree of 3-D distortion. The need for accuracy has been the driving force in the evolution of impression materials. Elastomeric impression materials have been found to capture surface detail better than inelastic materials and were associated with fewer defects (Johnson, Lepe and Aw, 2003). In order to improve their clinical performance, polyethers and polyvinyl siloxanes have been modified to improve their hydrophilicity to the degree where they are classified as being ‘moderately hydrophilic’ (Takahashi and Finger 1991; Johnson et al, 2003). Differences exist between and within the polyvinyl siloxane and polyether groups due to the modifications to improve their accuracy. It is best to investigate which of the impression materials displays the greatest dimensional stability so that the selection made would be evidence-based. The literature has of necessity presented predominantly in vitro studies. Some of these studies have tried to simulate the moist to wet oral conditions which does not seem to be clinically relevant (saliva and blood behave differently from water) (Tenovuo, 1989 cited in Petrie et al, 2003). The studies performed under dry conditions could provide better evidence in that it is possible to get moisture control intra-orally using traditional ways. Any bleeding can be controlled via a variety of methods which were shown not to affect dimensional accuracy (Johnson et al, 2003).

In an in vitro study by Johnson et al (2003) significant differences were found between polyether and PVS impression materials under moist conditions, and between single viscosity versus dual viscosity impression materials under wet and dry conditions. Under conditions where moisture is difficult to control, polyether was shown to be the better choice for an impression material. In terms of surface detail, polyether was better compared with PVS, as were the monophase materials compared with the dual phase materials.

In a study similar to the proposed study, Von Berg (2007) investigated the accuracy of polyether versus plaster impressions. He demonstrated distortion between impressions and master casts relative to master models and concluded that it was not possible to make an undistorted impression or cast. The dimensions of the impression and the resultant master cast were compared to a steel master model under dry conditions. Both impression materials showed expansive distortion and the horizontal dimensions between implant analogues tended to increase with both impression materials. These findings supported those of Linke, Nicholls and Faucher (1985). The plaster impressions were associated with less distortion than polyether while polyether impressions showed greater consistency and hence reliability compared with the less predictable plaster impressions.

Stober et al (2010) in an in-vitro study examined the properties and performance of PVS, polyether and the hybrid product vinyl siloxanether (containing combined properties of hydrophilicity). Results obtained with respect to accuracy of these materials from their non-disinfected group studied showed comparable results, and the differences compared to the master model were small. Considering that the accuracy of the casts was high, differences between the impression materials were irrelevant.

3 Rationale of the Study

The literature has shown that implant maintenance is very costly from a biological, time, convenience and economic perspective. Mechanical failures are commonly due to a non-passive fit of the metal substructure. This investigation thus seeks to find the impression material associated with the least degree of distortion in order to assist the achievement of passivity of fit thereby reducing complications. It is envisaged that the proposed study would establish which of the four materials creates the least distortion in long-span implant supported prostheses. This contribution to the advancement of fit would ultimately improve clinical care.

4 Aims and Objectives of the Study

4.1 Aims

- To evaluate the dimensional accuracy with which the impression materials to be tested (Plastogum, Impregum, Aquasil monophase and Aquasil putty-wash) reproduce implant positions from a stainless steel master model containing five analogues
- To compare the accuracy of the subsequent casts
- To compare the dimensional accuracy of the single viscosity elastomers with the dual phase PVS.

4.2 Objectives

- To measure the implant positions (all placed parallel to each other) of the stainless steel master model, their positions in the impressions, and in the resultant mastercasts.
- To calculate the differences between:
    - The master model and the impressions
    - The impressions and their master casts
    - The master models and the master cast

5 Methodology

5.1 Study Design

The study is a laboratory-based comparative study based on measurements taken of inter-implant positions captured in the impressions and their resultant stone casts. These are described and compared in terms of degree of distortion. This information is also compared with the results of similar studies globally in order to provide greater statistical power to a study with a limited sample size and to contextualize the findings within a broader framework of research of this nature.

5.2 Sample Size

A sample size of 5 per impression material was found to be adequate to detect clinically relevant differences. This was shown by a number of studies in the literature which act as pilot studies. A sample size of 5 was shown to have clinical accuracy of ± 7µm for antero-posterior and cross-arch dimensions, ± 5µm for mesiodistal and buccolingual dimensions, and ± 10µm occluso-gingival dimensions (within a 95% confidence interval) (Stober et al, 2010, Johnson et al, 2003, Kronström et al, 2010, Wadhwani et al, 2005).

5.3 Materials and Methods

A stainless steel master model was used to mimic a dental arch containing five implant analogues (Southern Implants Irene, South Africa) (figure 1).

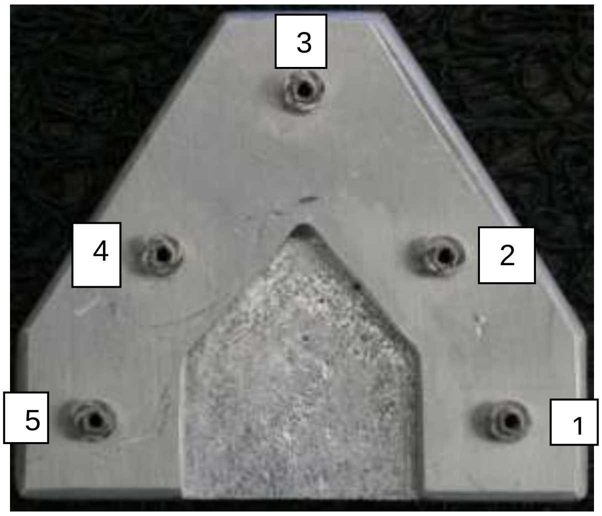

Fig. 1 Master model containing five standard implants

The information regarding implant position was captured using the four impression materials under investigation: Plastogum, Impregum Penta, Aquasil Ultra Monophase and Aquasil Putty Deca with Ultra LV Regular. Each material was mixed strictly according to the manufacturers' instructions.

Spaced (3mm) special trays were standardised as follows: a cast was poured from an Impregum Penta impression of the master model containing transfer copings and guide pins. A double spacer made from Bioplast mouthguard material 125X 3mm (Nova Dental Laboratory Supplies, South Africa) was vacuum formed over the resultant stone cast (figure 2). The stone cast covered with the spacer was duplicated using Wirosil duplicating silicone material (Nova Dental, South Africa) (figure 3). A stone cast obtained from the silicone mould (figures 3 and 4) was used onto which light-cured acrylic (Megatray, Megadent) was formed (figure 5). Windows were cut into each tray for future exposure of the transfer copings and guide pins.

Fig 2. Vacuum-formed 3mm spacer

Fig 3. Wirosil impression of mastercast covered with 3mm spacer

Fig 4. Wirosil impression used to cast a model onto which special trays are to be made

Fig 5. Spaced special tray

Two coats of adhesive were painted onto the special trays, separated by 15 minutes' drying time. ESPE polyether adhesive was used for the Impregum impressions and Fix PVS adhesive for the Aquasil impressions.

Fifty impression copings (CBU, Southern Implants) were used for the first two impression materials (Polyether and PVS monophase) impression materials (5 copings for each impression). The same 50 impression copings were re- used for the subsequent impression materials.

Impressions were taken in a controlled environment with temperatures ranging from 19.5 °C to 21°C (as measured per room thermometer) and left for at least 7 minutes before removal from the master model (figure 6 gives an example of an Impregum impression). After removal and measurement, stainless steel implant analogues (LS12, Southern Implants) were attached to the precision impression copings and torqued to 10 Ncm with a Southern Implant torque wrench.

The casts were poured in Satin stone (Pemaco, St Louis, MO, USA) a type IV dental stone with 0.07 expansion after 2 hours (stored at 24ºC) (figure 7), and was left to set at 21ºC. The stone was carefully weighed out (100g) for exactness and consistency, a correct amount of distilled water (19mm), and vacuum mixed for the same length of time (1 minute at 21ºC which is according to the manufacturer’s specifications).

Fig 6. Impregum Penta impression

Fig 7. Master cast made from Satin stone

5.4 Measurements

Measurements were made on the master model, the impressions, and the resulting master casts in a temperature controlled environment (22ºC) (figure 8).

Fig 8. Measurements taken on the master model, the impression and the master cast for the 5 implant positions numbered 1-5: each inter-implant distance was measured.

Measurements were made with a portable co-ordinate measuring machine (PowerINSPECT, Delcam, UK) which for these measurements operates at an accuracy of 4µm. The measuring arm ends in a ball probe laser scanner (figure 9). When placed over the implant, the impression coping or the laboratory analogue, it scans the midpoint of each implant to give a three-dimensional representation of that position (figure 10).

Fig 9. Point probe laser scanner on master model.

Fig 10. Point probe CAD scanner scanning an impression coping in the PVS impression in its special tray. All impression trays were placed on a flat custom-made base to prevent movement during scanning.

Ten distances (1-2, 1-3, 1-4, 1-5, 2-3, 2-4, 2-5, 3-4, 3-5, and 4-5) were therefore measured for each inter-implant distance for the master model, each impression and each mastercast. All measurements were made in a temperature controlled environment at 22ºC. The master model was measured before and after each impression material to ensure positional stability throughout the project.

Measurements made were documented on a computer via a direct link. The XYZ co-ordinates of each implant position were recorded and from this information, the 3-D inter-implant distances were calculated for each impression, resultant mastercast and the master model. Measurements of the impressions (a negative copy of the master model) were taken in reverse order (figure 8) so that the inter-implant distances are being compared.

Steps:

- Day 1 (AZ Tech lab): Measurements of the five implant positions were taken of the stainless steel model using the Cad Probe Scanner and measurements were recorded for each of the 10 inter-implant positions on a linked computer
- Day 2 (Brånemark Institute): 5 Impregum Penta and 5 Aquasil Ultra DECA Monophase impressions were made of the master model and left to set for 24 hours
- Day 3 (AZ Tech lab): 5 measurements of the implant positions were taken (as before) for each Impregum Penta impression and 5 for each Aquasil Ultra DECA Monophase impression
- Day 4 (D'Eurodental laboratory): 5 Satin stone models from the Impregum Penta impressions and, 5 Aquasil Ultra DECA Monophase impressions were poured and left to set for 24 hours
- Day 5 (AZ Tech lab): 5 measurements of implant positions were taken (as before) of the casts from each of the Impregum Penta plaster models and from each of the Aquasil Ultra DECA Monophase impressions
- Day 6 (Brånemark Institute): 5 Aquasil (Putty Deca and Ultra LV Regular Set) and 5 Plastogum impressions were made of the master model and left to set for 24 hours
- Day 7 (AZ Tech lab): 5 measurements of the implant positions were taken (as before) for each Aquasil (Putty Deca and Ultra LV Regular Set) impression and 5 for each Plastogum impression
- Day 8 (D'Eurodental laboratory): Stone models were poured from the Aquasil (Putty Deca and Ultra LV Regular Set) and Plastogum impressions, and left to set for 24 hours

- Day 9 (AZ Tech lab): Implant positions were measured as before for each of the resultant stone casts

Note: The master model was measured 6 times to ensure consistency of the coping positions throughout the process

5.5 Data Analysis

The above data were captured in MS-Excel and the information was imported into a statistical package (Statistical Package and Service Solutions (SPSS) Inc, Chicago, USA). A 1-factor t-test was used to analyse the data. The factors assessed were that of inter-implant distance and total arch distance for the various impression materials and techniques employed.

This information enabled a descriptive analysis that yielded inter-implant regions where expansive or contractive distortion occurred. A description could be made of those areas where distortion was common to all the impression materials under investigation and allowed for the identification of common patterns and frequencies of distortion within the arch.

The analysed data also allowed for the quantification of the extent of the differences in distortion.

5.6 Validity

This study design ensured that quality data were collected and that, where possible, biases were minimised or eliminated. The same operator performed all the tasks (impression, casting and measurements of models). Impression materials were taken from a single batch (the same lot number) for the four different materials. The mixture of the materials was performed as per manufacturer's directions keeping the consistency and temperature of the mixtures constant.

The co-ordinate measuring machine was calibrated (task performed at least once a month and approved by the CSIR), and was fully operational as verified by the Managing Director of AZ Technology, the owners of the device. The device displayed intra-reader reliability as repetitive measurement of the distances was exactly the same for each distance i.e. there was no variation. Excluded from the data set were any models that contained obvious distortions as a result of operator errors (drag, air bubbles). The methodology included a final check on the data for internal consistency.

5.7 Limitations of the Study

This investigation did not simulate the oral conditions and must therefore be interpreted cautiously. Still, the outcomes of the study are relevant and prove useful. *In vitro* studies under dry conditions have been shown to provide predictable results, which is an environment which can be achieved clinically. Moisture control can be achieved in a traditional way, and slight bleeding can be controlled via astringent which has been shown not to affect dimensional stability (O'Mahony et al, 2000).

6 Results

Table 1 shows the averages of all the measurements made. Highlighted figures represent inter-implant distances where distortion was statistically significantly different from the master model. The table shows positive differences representing expansion in red and negative differences representing contraction, in yellow.

Table 2 and figure 11 reflect the absolute value of the differences that exist between the average sample distances (x) for each material being investigated and the master model (μ). It puts the null hypothesis to the test which assumes that: x =μ= zero, which means there should be no difference between the average of the samples and the test values i.e. zero distortion.

Table 1. Average (of ten) interpositional distances (mm) for the master model, impression materials and master casts. Highlighted figures represent inter-implant distances where distortion is statistically significantly different from the master model; yellow represents contraction and red, expansion.

Groups	Interpositional Implant distances (mm)								
	Impressions					Casts			
	Master model (Test value)	Impregum	Aquasil Mono-phase	Putty and Light body	Plastogum	From Impregum	From Aquasil	From Putty + light body	From Plastogum
1-2	21.5350	21.4784	21.5210	21.434	21.968	21.490	21.481	20.420	21.776
1-3	47.0990	47.0430	47.1268	47.442	47.642	47.116	47.121	46.144	46.908
1-4	46.5410	46.5320	46.5258	47.624	46.542	46.537	46.502	45.912	45.908
1-5	50.0340	50.0332	50.0634	50.958	49.834	50.075	50.015	49.438	49.562
2-3	26.1720	26.1986	26.2508	26.578	26.338	26.253	26.267	26.426	26.028
2-4	34.0000	34.0428	34.0306	33.848	34.080	34.034	34.013	34.142	34.258
2-5	46.4860	46.5490	46.5510	45.948	46.616	46.571	46.520	46.456	47.314
3-4	26.2690	26.1284	26.2424	25.880	26.776	26.170	26.181	25.574	26.466
3-5	47.1140	47.0430	47.1440	46.974	47.626	47.100	47.081	46.710	47.704
4-5	21.4710	21.5450	21.4890	21.672	21.470	21.545	21.512	21.846	21.838

Table 2. Absolute value of the average differences between the impression materials and the master casts to the test value

Groups	Absolute values of the differences								
	Impressions					Casts			
	Master model (Test value)	Impregum	Aquasil Mono-Phase	Putty and Light body	Plastogum	From Impregum	From Aquasil	From Putty + light body	From Plastogum
1-2	0.00	0.057	0.014	0.101	0.433	0.045	0.054	1.115	0.241
1-3	0.00	0.056	0.028	0.343	0.543	0.017	0.022	0.955	0.191
1-4	0.00	0.009	0.015	1.083	0.001	0.004	0.039	0.629	0.633
1-5	0.00	0.001	0.029	0.924	0.200	0.041	0.019	0.596	0.472
2-3	0.00	0.027	0.079	0.406	0.166	0.081	0.095	0.254	0.144
2-4	0.00	0.043	0.031	0.152	0.080	0.034	0.013	0.142	0.258
2-5	0.00	0.063	0.065	0.538	0.130	0.085	0.034	0.030	0.828
3-4	0.00	0.141	0.027	0.389	0.507	0.099	0.088	0.695	0.197
3-5	0.00	0.071	0.030	0.140	0.512	0.014	0.033	0.404	0.590
4-5	0.00	0.074	0.018	0.201	0.001	0.074	0.041	0.375	0.367

Figure 11 depicts the values in table 2 graphically. Together these reflect the deviation of the sample averages x (for each of the impression materials and their respective casts) relative to the baseline value (test value where $\mu = 0$).

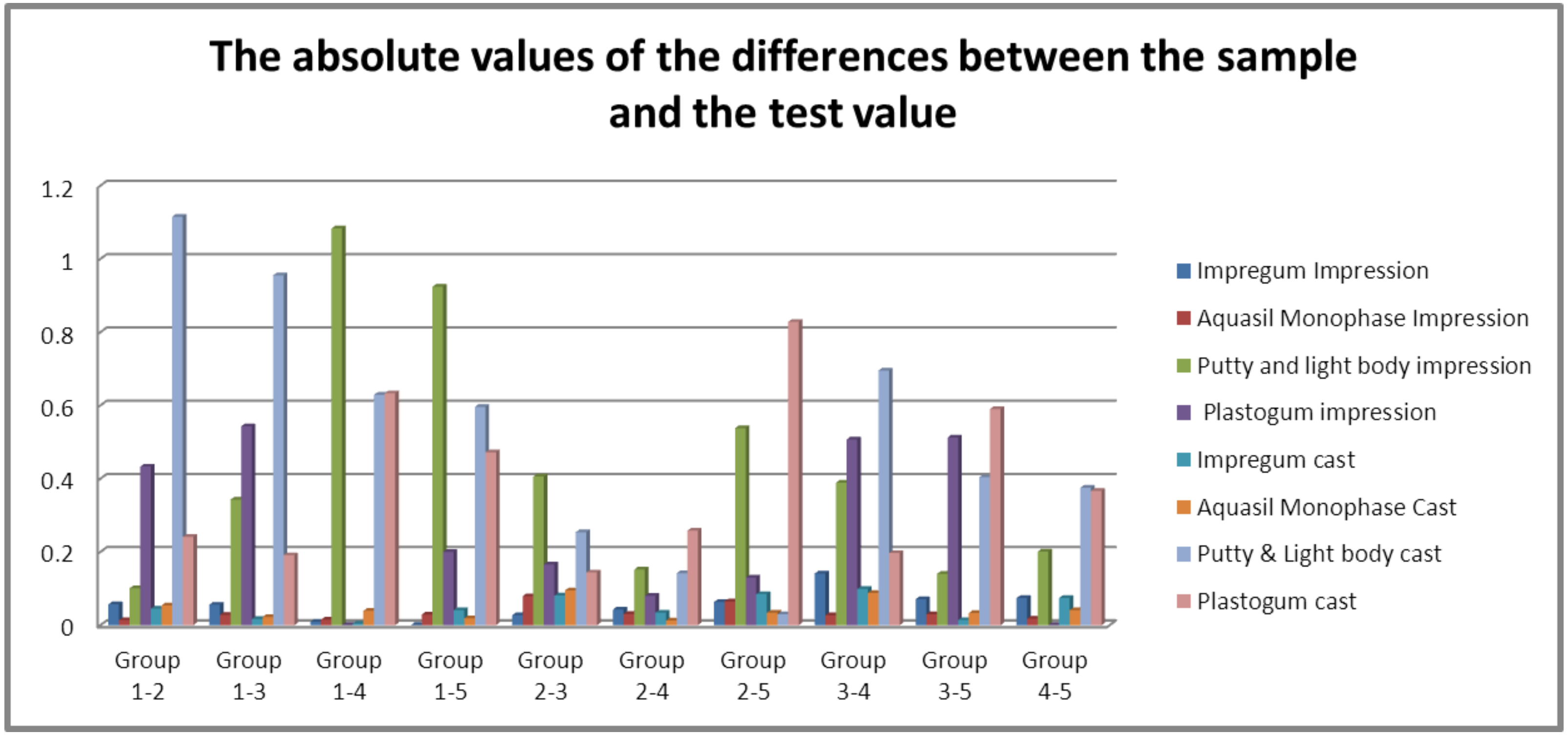

Fig. 11 Absolute values of the average differences between the samples and the test value. Note: The impressions and their resultant casts are examined independently.

Table 3 compares the impressions with their subsequent casts.

Table 3. Comparison of averages between the impressions and their respective casts

	Interpositional Implant distances (mm)											
Measure -ments	**Imp impression**	**Imp casts**	**P values**	**Aquasil impression**	**Aquasil casts**	**P values**	**Putty + LB impression**	**Putty + LB casts**	**P values**	**Plastogum impression**	**Plastogum casts**	**P values**
1-2	21.4784	21.490	0.323	21.5210	21.481	0.421	21.434	20.420	0.304	21.968	21.776	0.656
1-3	47.0430	47.116	0.117	47.1268	47.121	0.903	47.442	46.144	0.068	47.642	46.908	0.173
1-4	46.5320	46.537	0.830	46.5258	46.502	0.238	47.624	45.912	0.022	46.542	45.908	0.151
1-5	50.0332	50.075	0.428	50.0634	50.015	0.112	50.958	49.438	0.002	49.834	49.562	0.460
2-3	26.1986	26.253	0.180	26.2508	26.267	0.751	26.578	26.426	0.839	26.338	26.028	0.463
2-4	34.0428	34.034	0.682	34.0306	34.013	0.552	33.848	34.142	0.329	34.080	34.258	0.570
2-5	46.5490	46.571	0.705	46.5510	46.520	0.351	45.948	46.456	0.428	46.616	47.314	0.058
3-4	26.1284	26.170	0.202	26.2424	26.181	0.372	25.880	25.574	0.681	26.776	26,466	0.227
3-5	47.0430	47.100	0.207	47.1440	47.081	0.442	46.974	46.710	0.755	47.626	47.704	0.866
4-5	21.5450	21.545	0.983	21.4890	21.512	0.295	21.672	21.846	0.403	21.470	21.838	0.197

Statistically significant differences are highlighted in yellow which suggests contractive distortion from the impressions to the resultant master casts. There were only 2 incidences of significant distortion in inter-implant positions 1-4 and 1-5 out of a total of 40 possible positions when comparing the impressions with their resultant casts.

Table 4 shows the differences in total arch distances between the master model and the resultant casts.

Table 4. Comparison of total arch distances between the master model, and the casts from the different impression materials.

	Test value = 366.721					
Distance Sum	**t**	**df**	**P –value (2-tailed)**	**Mean Difference**	**95% confidence interval of the difference**	
					Lower	**Upper**
Impregum	1.909	4	.129	.17140	-.0778	.4206
Aquasil	-.822	4	.457	-.02820	-.1235	.0671
Putty+ LB	-1.814	4	.144	-3.65300	-9.2455	1.9395
Plastogum	.773	4	.483	1.04100	-2.6971	4.7791

The total arch distances of the resultant mastercasts of the various impression materials are not significantly different from the master model.

7 Discussion

Under the strict conditions of this *in vitro* study, the results have shown that distortion is inevitable. This is clear from the inferential and descriptive statistics discussed below. *In vitro* studies by Johnson et al (2003), Von Berg (2007), Stober et al (2010) and others, reinforce these findings. The prediction as to the cause of any distortion and at which point during the procedures distortion occurs is difficult to establish.

According to table 1 which gives a summary of the averages of the inter-implant distances, inferential statistics were used to indicate which materials showed significant distortion at the various positions.

Interestingly, there were no statistically significant differences found between the Aquasil monophase impression and the master model, or between the impressions and their resultant casts, but there were differences between those casts and the master model. Similarly, this was the case for Plastogum. However, there are four PVS Monophase and five Plastogum incidences of significant difference between the master model and the mastercasts for these materials. These results highlight the cumulative effect of distortions (which were present but not significant in the preceding steps) but which ultimately yielded master casts with significant inter-implant distortions.

Similarly, for Impregum, the cumulative nature of distortion has ultimately yielded 6 instances of distortion between the mastercast and master model.

PVS (putty with light body) is the only material that displayed distortion during the impression stage which later seemed to be ‘reversed’ where the significant distortions that previously existed were no longer significant. Looking more closely at the average values for each of the interpositional group measurements for this material, a great deviation is displayed relative to the master model, and particularly compared with other materials under investigation. These findings indicate the importance of a correct interpretation of pure statistics. The finding of statistical significance does not always explain the clinical or practical significance of the behaviour of materials. A possible yet not probable explanation for this ‘reversal’ of significant distortion could be speculated: the initial expansive distortion could in part be negated by a contractive distortion in the master cast as is evident in instances for group 1-4 and 1-5, and vice versa for group 2-5 where contractive distortion in the impression could be negated by expansion in the resultant cast in the same position (referring to table 1).

The practical limitation of the statistics is further highlighted by the observations of clinical significance where it was unexpected (as with the values of Impregum which displayed values closer to the master model than PVS putty with light body and Plastogum). Also, as with PVS putty with light body, instances where significant differences were expected due to greater deviation from the master model observed in table 2 and figure 11 (particularly compared with the other materials) did not show significant differences statistically as displayed in table 1.

This can best be explained by looking at the factors that influence significance. The variability within the samples measured (reflected by the standard deviation) play a great role in dictating the significances observed in table 1. Assuming an unknown variance initially, the following test statistic was used to investigate significance.

$$t = \frac{\overline{x} - \mu_0}{s/\sqrt{n}}$$

Where t is the t-statistic;

$\bar{x}$ is the average sample distances (x) for each material being investigated

μ is the master model (μ)

s is the standard deviation of the distance measurements and

n is the sample size for each material being investigated

This equation highlights the dependence of significance on the variability of the samples investigated. The greater the standard deviation for each test statistic, the greater the probability of failing to reject the null hypothesis (i.e. no significant differences relative to the master model) which also provides an explanation for the unexpected outcomes observed. Assuming that the sample averages follow a normal distribution and that a 2-sided test needs to be used (since distortion can be either expansive or contractive as is evident from the measurements taken), and for 4 degrees of freedom (n-1), an exact p-value is supplied by the statistical packages from the table of the t distribution. In clinical or practical terms, the statistical significance may not be totally applicable or useful when deciding on the material with the least distortion.

However, what is useful about the set of results obtained from inferential statistics is that they highlighted the three-dimensional changes that occurred which are of concern considering that these impressions and their casts were made under very strict laboratory conditions. It is thus highly probable that under clinical conditions the differences observed would be greater.

Another positive contribution of this line of investigation is the quantification of the variability that exists for the different materials by way of standard deviation measurements, and the range of each data set (obtained from the table in the Appendix showing the standard deviation and the range of each of the materials). These data indicate that Impregum generally had the lowest degree of variability, followed by Aquasil Monophase, PVS putty with light body and lastly Plastogum at the impression stage. Plastogum was shown to be the least reliable as an impression material and Impregum the most reliable. In the study by Von Berg (2007), Plastogum also showed less reliability compared with Impregum.

The results presented in table 2 and figure 11 provide data which are useful to interpret practically and more relevant clinically as the absolute values show deviation of all the impression materials and their mastercasts from the master model, but with no discernible pattern or consistency. Ideally of course, when searching for the impression material with the least distortion, its deviation from the master model needs to approximate zero more closely than its counterparts.

A quantification of the deviation from the master model shows that Aquasil putty with light body showed the greatest deviation in 7/10 instances spread over the various interpositional distances; Plastogum which showed the greatest deviation in 3/10 groups, and the second greatest deviation in 5/10 groups; Impregum showed less deviation than the above 2 materials with the least deviation in 3/10 instances and the second least in 6/10 instances; Aquasil Monophase showed the least deviation in 5/10 instances, and the second least deviation in 4/10 instances. Interestingly, Aquasil Monophase at the impression level is associated with the least distortion.

With respect to the resultant mastercasts for the various impression materials, the greatest deviation existed once again with the Aquasil putty with light body where

6/10 instances showed the greatest deviation and 3/10 of the second greatest deviation; Plastogum showed 4/10 instances with the greatest deviation and 6/10 of the second greatest deviation; Impregum showed 3/10 instances of the deviation and 4/10 instances of the second least; and Aquasil monophase showed the least deviation in 3/10 instances and 6/10 of the second least. At the mastercast level, Aquasil has shown the least deviation from the master model.

In terms of overall performance, Aquasil Monophase and Impregum Penta displayed the least distortion. A study comparing PVS with polyether showed no significant differences under dry conditions but polyether showed improved dimensional stability under moist conditions (Johnson et al, 2003) which may explain its wide usage. Investigations under moist conditions do not provide conclusive evidence for the behaviour of impression materials as they do not simulate the oral environment where blood and saliva is responsible for the moisture.

The dual viscosity material (Aquasil putty with light body) showed the greatest deviation relative to the monophase materials, which is reinforced by Johnson et al (2003) where the PVS monophase showed less distortion under wet and dry conditions.

In summary, the use of inferential statistics in a study of this nature, whilst providing evidence of distortion was unable to provide explanations for the clinical significance of the absolute values, where apparently large discrepancies have no statistical significance and small ones do. Therefore the descriptive data need to be viewed together with the statistical data. The descriptive data in table 2 can be used to explain the pure statistics in table 1. If the absolute value of the differences between samples and test value observed is divided by the standard deviation, a ratio (of differences) is obtained. This ratio influences statistical significance in that the larger the ratio, the higher the probability of rejection of the null hypothesis (i.e. the higher the probability of finding statistically significant results). This explains such findings as for example in the case of Impregum, which had the lowest standard deviation and therefore a larger ratio compared with PVS putty with light body and Plastogum which had much larger standard deviation values (increased variability and a greater range of results) and a smaller ratio.

The lack of statistically significant differences across total arch distances demonstrated in this study (reflected in table 4) suggests that there is no statistically significant distortion across the total arch distance for all the impression materials. Von Berg (2007) found overall expansive distortion of Impregum and Plastogum casts with the former showing greater distortion. These sets of measurements seem to be irrelevant in that they do not reflect the incidences of interpositional differences or distortions which are critical to the passivity of fit around specific implants. The total arch measurements mask the distortions (represented in table 1) within the arch because expansive distortion may be followed by contractive distortion which is not considered in the overall result. Examples of these can be seen with Impregum casts where there is expansive distortion between position 2-3 followed by contractive distortion between 3-4 which could negate each other and is ignored in a measure such as that of the total arch.

The differences between impressions and mastercasts in table 3 showed no statistically significant differences with the exception of PVS putty with light body.

Differences in position 1-4 (p=0.022) and 1-5 (p=0.002) represent 2 out of a total of 40 possible positions which reflects the accuracy of the procedure and that of the Satin stone used.

It has been suggested that distortion could be minimised by splinting implants with self-cure resins or plaster prior to the impression. However, according to Interregui et al (1993), there appears to be no clinical advantage to this.

Overall, then, the patterns of distortion appear random. Given this unpredictability, other means of registration of implant position needs to be provided to the laboratory for prosthesis fabrication such as the use of digital technology which could bypass the need for impressions and casts.

8 Conclusion

Under the conditions of this study the following conclusions can be drawn:

Three-dimensional distortion is inevitable and was displayed by all four impression materials under investigation.

Aquasil Monophase reproduced the master model most accurately. Impressions showed no significant distortion from the master model or between the impressions and the master casts. Distortions between the master model and the master cast highlight the cumulative effects of the observed changes.

Impregum showed three-dimensional distortion when compared with the master model and with casts poured from the impressions. Its performance proved to be the most reliable in terms of predictability.

Plastogum displayed cumulative distortion with no significant distortion in the impression stage but showed significant changes between the master model and the master casts. Together with Aquasil putty with light body, these impression materials had the least reliability.

It is likely that these distortions will contribute to lack of passivity of fit of superstructures. The unpredictability of such distortions, together with the evidence that one-piece castings also display unpredictable three-dimensional distortion (Mitha, Owen, Howes, 2009) may mean that the future of accurate impressions and superstructures may lie in the digital world.

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Appendix

				model Model							
				Impression				Cast			
				material Material				material Material			
				Impregum	Aquasil	PVS	Plastogum	Impregum	Aquasil	PVS	Plastogum
group Group	Group 1_2	distance	Mean	21.478	21.521	21.434	21.968	21.490	21.481	20.420	21.776
			Std. Dev	.022	.086	.427	.491	.011	.060	2.018	.788
			Min	21.459	21.438	20.870	21.520	21.478	21.414	18.110	20.630
			Max	21.515	21.662	21.950	22.620	21.504	21.575	22.390	22.730
			Range	.056	.224	1.080	1.100	.026	.161	4.280	2.100
	Group 1_3	distance	Mean	47.043	47.127	47.442	47.642	47.116	47.121	46.144	46.908
			Std. Dev	.083	.093	.931	.595	.042	.037	1.015	.922
			Min	46.897	47.036	46.450	46.970	47.086	47.065	44.750	45.680
			Max	47.096	47.275	48.760	48.340	47.187	47.158	47.280	47.950
			Range	.199	.239	2.310	1.370	.101	.093	2.530	2.270
	Group 1_4	distance	Mean	46.532	46.526	47.624	46.542	46.537	46.502	45.912	45.908
			Std. Dev	.042	.027	.345	.674	.024	.032	1.096	.586
			Min	46.484	46.488	47.330	45.690	46.511	46.451	44.850	45.150
			Max	46.596	46.557	48.200	47.520	46.576	46.534	47.700	46.580
			Range	.112	.069	.870	1.830	.065	.083	2.850	1.430
	Group 1_5	distance	Mean	50.033	50.063	50.958	49.834	50.075	50.015	49.438	49.562
			Std. Dev	.111	.043	.260	.473	.023	.042	.542	.624
			Min	49.841	50.024	50.570	49.080	50.041	49.952	48.570	48.670
			Max	50.100	50.134	51.240	50.220	50.105	50.054	50.010	50.040
			Range	.259	.110	.670	1.140	.064	.102	1.440	1.370
	Group 2_3	distance	Mean	26.199	26.251	26.578	26.338	26.253	26.267	26.426	26.028
			Std. Dev	.074	.094	.850	.487	.038	.056	1.381	.756
			Min	26.079	26.131	25.590	25.860	26.226	26.170	24.390	24.810
			Max	26.255	26.357	27.350	27.050	26.320	26.308	27.800	26.590
			Range	.176	.226	1.760	1.190	.094	.138	3.410	1.780
	Group 2_4	distance	Mean	34.043	34.031	33.848	34.080	34.034	34.013	34.142	34.258
			Std. Dev	.033	.059	.302	.660	.032	.027	.556	.131
			Min	34.008	33.939	33.460	33.270	34.007	33.982	33.520	34.110
			Max	34.094	34.078	34.190	34.970	34.085	34.041	34.770	34.420
			Range	.086	.139	.730	1.700	.078	.059	1.250	.310
	Group 2_5	distance	Mean	46.549	46.551	45.948	46.616	46.571	46.520	46.456	47.314
			Std. Dev	.122	.069	.413	.622	.024	.017	1.296	.335
			Min	46.350	46.484	45.450	45.860	46.556	46.495	44.230	46.870
			Max	46.656	46.662	46.310	47.360	46.612	46.540	47.450	47.680
			Range	.306	.178	.860	1.500	.056	.045	3.220	.810
	Group 3_4	distance	Mean	26.128	26.242	25.880	26.776	26.170	26.181	25.574	26.466
			Std. Dev	.064	.143	.520	.516	.019	.028	1.515	.118
			Min	26.052	26.115	25.430	25.940	26.139	26.156	23.150	26.310
			Max	26.210	26.446	26.610	27.310	26.189	26.214	27.270	26.630
			Range	.158	.331	1.180	1.370	.050	.058	4.120	.320
	Group 3_5	distance	Mean	47.043	47.144	46.974	47.626	47.100	47.081	46.710	47.704
			Std. Dev	.079	.172	.743	.905	.050	.029	1.673	.321
			Min	46.978	46.952	45.850	46.230	47.062	47.038	43.930	47.300
			Max	47.145	47.356	47.930	48.380	47.186	47.110	48.440	48.100
			Range	.167	.404	2.080	2.150	.124	.072	4.510	.800
	Group 4_5	distance	Mean	21.545	21.489	21.672	21.470	21.545	21.512	21.846	21.838
			Std. Dev	.012	.039	.427	.506	.039	.025	.107	.294
			Min	21.532	21.440	20.960	20.970	21.520	21.477	21.700	21.390
			Max	21.559	21.533	22.010	22.280	21.614	21.537	21.950	22.200
			Range	.027	.093	1.050	1.310	.094	.060	.250	.810