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A Comparison of Dimensional Accuracy Between Three Different Addition Cured Silicone Impression Materials

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Abstract - *Ten impressions of a metal implant abutment were made with each of three addition-cured silicone impression materials. Using the technique of co-ordinate metrology, the shoulder region of the abutment and corresponding regions of both impressions and dies made from these impressions were scanned and measured. Comparison of these measurements indicated that the mean dimension measured from the shoulder region for each group of impression materials was significantly different from those taken from the original metal implant abutment. However, when these impressions were cast in a gypsum based die material, none of the measured dimensions taken from the casts were significantly different from those taken from the original metal implant abutment. Thus, any change in measured dimensions occurring during impression making, was compensated for in some way by the casting process.*

KEY WORDS: Accuracy, Silicone impression, Addition cure.

INTRODUCTION

Impression materials have been used in the production of accurate replicas of the oral tissues since Philip Pfaff[1] reported making the first dental impressions in 1756. Since the 1980s, addition curing silicone impression materials have become the most widely used materials for impressions during crown and bridgework[2]. Detail of reproduction and dimensional stability are among their most important advantages, but their hydrophobic nature is their main disadvantage, not only because great care needs to be taken to avoid impression imperfections due to moisture but also casting with gypsum products can lead to void formation even with all appropriate precautions taken. This has led to a search for accurate hydrophilic silicone materials for use in the wet oral environment. These materials incorporate non-ionic surfactants, which by modifying the surface tension of the material make them more compatible with moisture. A consequence of this effect is that casting with gypsum products is said to be easier and void production is reduced. Other methods to improve wettability have been reported, for example topical applied surfactants[3], and disinfectants[4,5].

Pratten and Craig[6] showed one of these hydrophilic addition silicone materials to have a wettability similar to that of the superior polyethers. Fernandes *et al.*[7] analysed the effect of biological fluids such as saliva and blood on the impression surface and found that a biofilm firmly attached to the material did modify the surface tension.

The literature appears to confirm the advantages of hydrophilic polyvinyl siloxanes in terms of improved castability but the effects of these treatments on other properties of the impression material; such as dimensional stability has not been fully investigated. There is no scientific evidence to indicate that polyvinyl siloxanes advertised as "hydrophilic" can be syringed into a wet sulcus for an accurate impression[3,8].

Because of their ease of use, strength and cost, gypsum products are the most popular and widely used die materials used in dentistry, although these materials do not possess good wear resistance, nor do they reproduce surface detail as well as electroformed or epoxy dies because the surface of the set gypsum is porous at a microscopic level.

When set, all gypsum products show linear expansion. The setting expansion of high strength dental stone has been reported to be of 0.01% to 0.1[9,10] with about 70% of the expansion occurring during the first hour. This minimal expansion has been said to compensate for the dimensional changes inherent in the fabrication process of an indirect restoration. Setting expansion is affected by water/powder ratio, mixing type and time, addition of chemical compounds by the manufacturer and also immersion in water (hygroscopic expansion). Kakura *et al.*[11] evaluated setting expansion of dental stone poured in addition silicone impression materials and found that when hydrophilic silicone was used the setting expansion of dental stone was significantly more than that with hydrophobic silicone.

Where the construction of a restoration involves several stages, dimensional changes may occur at each stage. An expansion at one stage may compensate for contraction at another stage. For example, when constructing a cast metal restoration, the setting expansion of the investment material partially compensates for the casting shrinkage of the alloy.

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The information transfer that occurs from the impression (negative replica) to the cast of such impression (positive replica) should be achieved with as little distortion as possible. Assessment of distortion occurring in working casts and dies produced by different impression techniques has been reported by many workers, using a variety of methodologies. These include stereophotogrammetry[12], reflex microscopy[13], laser interferometry[14], scanning electron microscopy[15,16], microtomography[17], confocal microscopy[18] and mechanical digitisers[19]. For dental applications, surface measurement sensitive to changes at the microns level is necessary and current methods involving the use of three-dimensional Co-ordinate Measuring Machines are designed to meet these specifications[20].

One such method involves a computerised Co-ordinate Measuring Machine (CMM) that utilises a non-contact laser-scanning probe. The laser light-scanning probe records data from a series of closely separated points on a surface to define a feature. These optical systems determine the co-ordinate points on a surface by 'triangulation', which is directing light towards a surface in one direction and collecting the scattered light in a different direction. One such system has been shown to be reproducible and accurate[21], allowing measurement of distance in millimetres to three decimal places (1 micron) and angles to the nearest degree. Previous studies have quoted a reproducibility of ±7 microns[22].

Conventional addition silicones are extremely dimensionally stable, their expected change is about 0.1% within the first 24 hours and after this time the material remains stable for a long time[23,24].

The introduction of newer hydrophilic addition curing silicones, presents several reported advantages such as improved wettability, improved castability but the dimensional stability of these newer materials has not been investigated thoroughly.

Thus the aim of this study was to evaluate the dimensional accuracy of different addition curing silicone impression materials and a Type IV dental stone to reproduce the surface features of a machined metal die.

MATERIALS AND METHODS

A machined metal implant abutment (solid abutment 6, Height 5.5 mm, Ti, Ref. 048.541, Straumann AG) was customised by placing two reference dimples, one above and one below the shoulder region, with a small diameter centre punch (Department of Medical Physics, Barts and The London NHS Trust). A particular feature of the abutment was this shoulder region, which the manufacturers quote as being approximately 0.6mm in width at its widest point. The machined metal abutment was partially embedded in light curable acrylic resin and placed within a custom-made copper tray of 15x15x10 mm leaving the machined metal abutment exposed by an adequate amount for impression making and subsequent data collection. *Figure 1* shows the implant abutment embedded in the copper.

Figure 1. *Metal implant abutment embedded in the metal tray.*

The metal abutment was then scanned ten times by co-ordinate measuring machine (CMM) (Merlin 11, International Metrology Systems) utilising a non-contact 830 nm wavelength laser triangulation probe (Renishaw OP2).

The resulting images were analysed using the built in software (Accudat, International Metrology Systems). The shoulder region was identified, and the width of this shoulder then measured. Each image was measured 10 times by the same operator (LF-B). The measurements consisted of quantifying the width of the shoulder across the same area on each sample, between the two reference dimples.

Ten impressions were then made of the abutment in each of three polysilicone impression materials. The impressions were made so that the impression tray would contain the entire length of the metal abutment. The materials used were: two polyvinyl siloxane hydrophilic types and one traditional or hydrophobic type, namely: Perfexil (Specialites Septodont, Imprint II, 3M Dental Products, Extrude, Kerr UK).

The impressions of each material were made using a light /heavy body silicone technique within the metal special tray as per the manufacturers instructions. (See *Figure 2* for a photograph of the tray complete with an impression).

The trays were coated individually with the appropriate tray adhesive and left to dry for 30 minutes prior to making the impressions. Placing the tray over the abutment, light wash was firstly syringed directly onto the metal die followed by the heavy body. Finally a metal tray lid was placed on the impression until it contacted the sides of the tray and held with constant pressure until the material has set. The metal lid was removed after 10 minutes, at which time the impression material had set completely. At this point the impressions were ready to be removed from the metal abutment.

The impressions were scanned by CMM as described previously. The shoulder region was identified, and the

Figure 2. *An example of an Imprint II impression within the metal tray.*

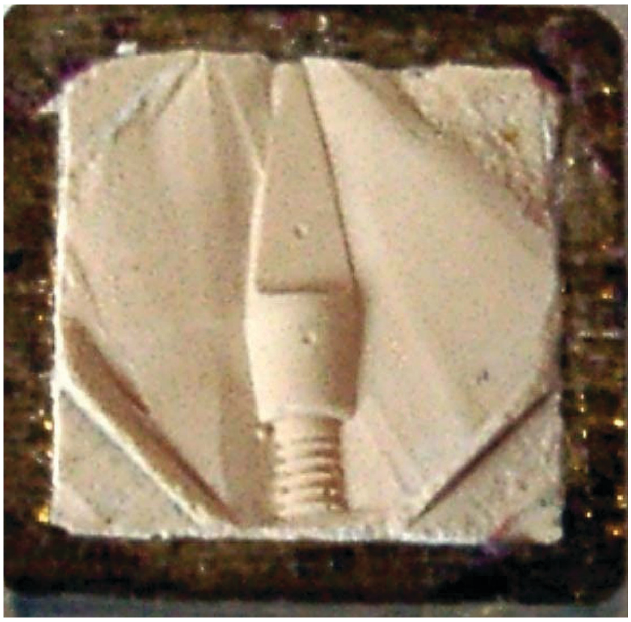

Figure 3. *Stone die within the metal impression tray.*

width of this shoulder then measured. Each image was measured 10 times by the same operator (LF-B). The measurements consisted of quantifying the width of the shoulder across the same area on each sample, between the two reference dimples.

Each group of impressions were stored for 24 hours before pouring with a Type IV dental stone (Fuji Rock, GC Europe). For this process, a similar metal impression tray was used and coated with petroleum jelly (Vaseline, Chesebrough-Pond's LTD) on the internal surface to facilitate separation of the stone from the tray.

The stone was prepared and vacuum mixed, according to the manufacturer's instructions. It was then left to set for two hours and then separated from the impression. All impressions and dies were made at room temperature. *Figure 3* shows an example of one of the stone dies inside its metal impression tray.

All dies were then scanned as described previously, and provided data from 100 measurements per group, i.e. the original metal die was scanned 10 times and each scan measured 10 times (100 measurements). Following this, 10 impressions were made of the metal die with each impression material. Every impression was scanned once and measured 10 times (100 measurements), each of these impressions was then cast. Each of the resulting cast was then scanned and each scan measured 10 times (100 measurements).This protocol was in line with previous work carried out by this group and is believed to minimise human measurement error[21,22]. An analysis of variance was carried out and followed by appropriate *post-hoc* tests, (in this case a Bonferroni test). *Figure 4* shows an example of one of the scans. *Figure 5* shows the plane along which the measurement of the shoulder width was made. *Figure 6* shows the profile taken through this plane, and from which the measurements were made. The measurement axes are also shown here. These are automatically generated by the software package and allow measurement in millimetres to three decimal places.

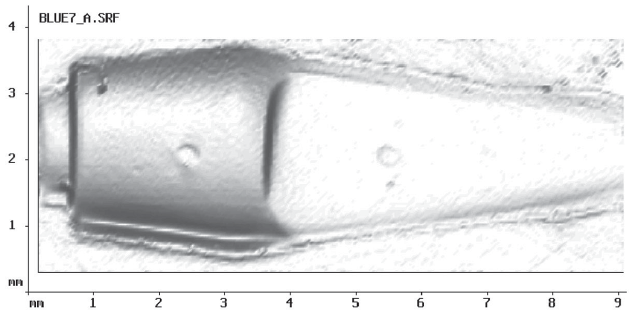

Figure 4. *Scan image.*

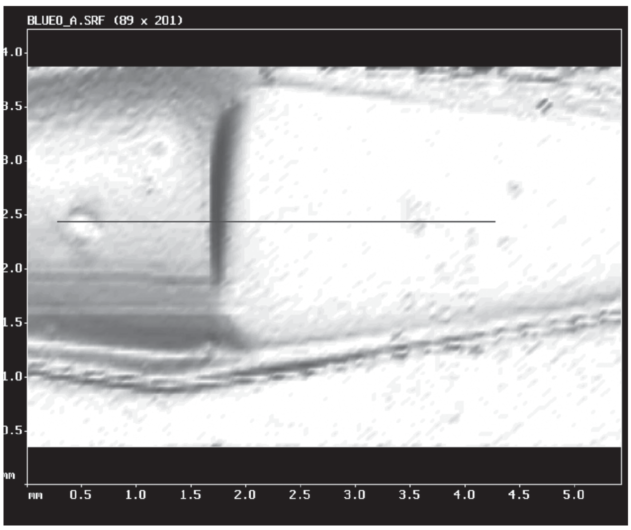

Figure 5. *Scan image showing the plane of measurement.*

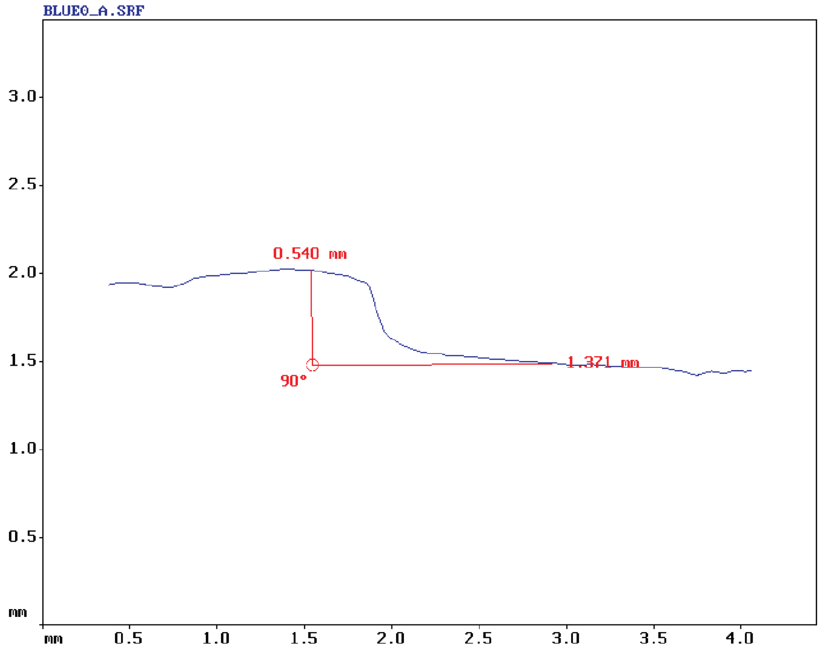

Figure 6. *Profile obtained from Figure 5, showing measurement axes.*

Table 1. *Mean data of measurements of shoulder widths.*

	Group 1 impressions	*Group 1 dies*	*Group 2 impressions*	*Group 2 dies*	*Group 3 impressions*	*Group 3 dies*	*Original die*
	0.525	0.670	0.521	0.652	0.567	0.616	0.642
	0.595	0.598	0.424	0.605	0.514	0.621	0.641
	0.489	0.689	0.480	0.761	0.512	0.671	0.638
	0.549	0.667	0.546	0.721	0.544	0.729	0.623
	0.574	0.652	0.497	0.585	0.524	0.623	0.642
	0.587	0.660	0.486	0.640	0.568	0.681	0.626
	0.568	0.661	0.530	0.678	0.532	0.659	0.630
	0.577	0.773	0.575	0.735	0.558	0.684	0.643
	0.586	0.658	0.479	0.674	0.558	0.622	0.638
	0.531	0.653	0.529	0.618	0.555	0.659	0.641
95% Confidence Interval	0.021	0.027	0.026	0.036	0.013	0.023	0.004
Mean	0.558	0.668	0.507	0.667	0.543	0.657	0.636
Standard Error	0.011	0.014	0.013	0.018	0.007	0.012	0.002
Standard Deviation	0.034	0.044	0.042	0.058	0.021	0.037	0.007
Minimum	0.489	0.598	0.424	0.585	0.512	0.616	0.623
Maximum	0.595	0.773	0.575	0.761	0.568	0.729	0.643

Group1 relates to impressions made in Extrude and their dies.
Group 2 relates to impressions made in Imprint II and their dies.
Group 3 relates to impressions made in Perfexil and their dies.

Table 2. *Bonferroni test where "x" indicates significant difference.*

	Group 1 impressions	*Group 1 dies*	*Group 2 impressions*	*Group 2 dies*	*Group 3 impressions*	*Group 3 dies*	*Original die*
Group 1 impressions		X		X		X	X
Group 1 dies	X		X		X		
Group 2 impressions		X		X		X	X
Group 2 dies	X		X		X		
Group 3 impressions		X		X		X	X
Group 3 dies	X		X		X		
Original die	X		X		X		

RESULTS

Table 1 shows grouped mean data from each of the ten impressions, ten dies and the original metal implant abutment, with the key to each group below. Measured dimensions are in mm. This is shown in *Table 2*; significant differences are given at the p<0.05 levels. The test showed that:

- Measured dimensions of the shoulder width from each group of impression materials were statistically significantly different from the original metal implant abutment.

- None of the measured dimensions of the shoulder width taken from the casts were statistically significantly different from those taken from the original metal implant abutment.

In general, it appeared that shoulder measured dimensions taken from all groups of impressions were smaller than the original, but that when cast in Type IV stone, these measurements were found to be analogous to the original shoulder width as measured directly from the original abutment.

DISCUSSION

The current practice in modern prosthodontics is to use polyvinyl siloxane for obtaining impressions of crown and bridge preparations, including implant abutments. Accuracy and dimensional stability are crucial factors that contribute to restoration longevity and ultimate success in restorative dentistry.

The aim of this study was to evaluate the dimensional accuracy of three different addition curing silicone impression materials and a Type IV dental stone to reproduce a machined metal implant abutment.

The study has shown that despite the fact that measured dimensions of shoulder width taken with all the impression materials were statistically significantly different from the original die, all the dies replicated the original metal die. Following casting in the gypsum-based product, the difference in shoulder width apparently disappeared, regardless of the difference between the measured dimensions of the impression and the original. Therefore, casting appears to have compensated for all the observed differences between the measured dimensions of the shoulder width of the impression material samples and the original metal die. This phenomenon is poorly understood however, silicone polymers are hydrophobic materials, so in the presence of blood/saliva defects occur in the cured impression. To overcome this problem, detergents are added to both condensation and addition silicone impression materials. The detergent confers a small degree of hydrophilicity and improves wettability[25].

Nowadays, there are a number of addition-curing silicones that are marketed as “hydrophilic” (e.g. Perfexil and Imprint II). These tend to have more detergents added to their formulation to overcome the silicone’s natural hydrophobicity. However, this may result in more water diffusing into the silicone material. The presence of hydrophilic groups in the material will encourage water uptake via polar or ionic attraction[26,27].

It is possible then that when a set hydrophilic addition curing silicone impression material is poured with stone, initially the water from the stone diffuses rapidly into the impression. The diffusion coefficient of water into silicones is very high (i.e. 10–9m2sec-1 at 35.9^{o}C)[28,29]. Nevertheless there were no significant differences between the hydrophilic and hydrophobic impression materials.

In our study, this water uptake could only have happened when the gypsum stone was poured into the impressions. The water loss from the gypsum stone may have affected the crystal growth and therefore the setting expansion of the stone. The clinical relevance of these findings is that all impression discrepancies from the original metal die were compensated in the end, although in some cases they were of a considerable size (up to 0.15 mm, or about 25%).

We found that neither of the hydrophilic impression materials showed a statistically significant difference to the hydrophobic group (Extrude) in terms of shoulder width measured dimensions. This implies that there may be no difference in the dimensional performance between the newer (hydrophilic) and the old type (hydrophobic) of silicone materials.

CONCLUSIONS

- Within the limits of the current study it can be concluded that:
- Measurements of impressions taken with 3 different types of materials using CMM showed statistically significant difference when measuring a shoulder on an implant abutment and comparing this to that on the original metal implant abutment.
- When these impressions are cast in a gypsum based die material, the difference is compensated for.
- If dies are compared, there is no statistical difference between those originating from hydrophilic and those originating from hydrophobic poly silicone impression materials.

Further research should investigate, in particular, the detailed nature of this apparent compensation of gypsum based die materials, and the dimensional relationship between materials at each stage of restoration construction, utilising the technique of co-ordinate metrology.

MANUFACTURERS’ DETAILS

- solid abutment 6, Height 5.5 mm, Ti, Ref. 048.541, Straumann AG, Switzerland
- Merlin 11, International Metrology Systems, Livingstone, UK
- OP2, Renishaw, Gloucester, UK
- Accudat, International Metrology Systems, UK
- Specialites Septodont, Saint-Maur-des-Fosses, Cedex, France
- Imprint II, 3M Dental Products, St Paul, Minnesota USA
- Extrude, Kerr UK, Peterborough, UK
- Fuji Rock, GC Europe, NV, Leuven, Belgium
- Vaseline, Chesebrough-Pond’s LTD, Leeds UK

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