The Effect of Sulcular Width on the Linear Accuracy of Impression Materials in the Presence of an Undercut

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Purpose: This study examined the effect of gingival sulcular width, in the presence of an undercut, on the accuracy of dies poured from impressions made with different impression materials. ***Materials and Methods:*** Three polyvinyl siloxanes (Examix, Elite, and Express), one polyether (Permadyne), and one polysulfide (Permlastic) were used to make impressions of six metal dies. The dies were machined to simulate teeth with a chamfer preparation, root convergence, and sulci of varying widths (0.10 to 0.40 mm). The impressions were poured with type IV stone, and the resulting dies were measured under a traveling microscope at the level of the finish line. The distortion of each die was calculated. ***Results:*** The distortion ranged from 0.01% to 0.89%. All materials showed similar behavior: At the narrowest sulcular width (0.10 mm), the distortion was considerably larger (0.43% to 0.89%) than at the wider sulci (up to 0.20% in most cases). Examix (polyvinyl siloxane), Permlastic (polysulfide), and Permadyne (polyether) gave the most accurate dies for sulci 0.15 mm and wider. Express (polyvinyl siloxane) showed greater deformation than other materials in most sulcular widths under the conditions of this study. ***Conclusion:*** Accurate impressions can be expected in sulci $\geqslant$ 0.15 mm in width at the level of the finish line coronal to an undercut. Impressions with 0.10-mm sulci widths are not predictable. The physical properties of the impression materials used cannot be anticipated based on their chemical group. *Int J Prosthodont 2004;17:585–589.*

When an impression is made, the material used should be capable of withstanding tearing and distortion when removed from the mouth and poured with stone. The accuracy and completeness of the impression's margins are influenced by the thickness of the margins[1] and the material's physical properties,[2–5] such as tear strength and permanent set (lack of recovery from deformation) or strain at yield point (which indicates the amount of undercut the impression material could overcome without permanent elastic deformation).

A previous study assessed different impression materials for accuracy and completeness of impression at different simulated gingival sulcular widths.[1] Distortion values were similar among the materials used to make impressions of abutments with sulcular widths of 0.2 to 0.4 mm. However, when the same materials were used with narrower sulci of 0.16 mm or less, differences appeared. A polyvinyl siloxane (Examix) and a polysulfide (Permlastic) exhibited results comparable to impressions of wider sulci, whereas a polyether (Permadyne) and another polyvinyl siloxane (Elite) showed greater distortions and coefficients of variance. Large coefficients of variance demonstrated the difficulty of consistently obtaining good impressions. Polysulfides as a group have higher tear strengths than do polyethers or polyvinyl siloxanes.[2–5] This is an advantage when a narrow sulcus is present. On the other hand, polysulfides have a low strain tolerance[2,3] that renders them liable to deformation when used to record undercut

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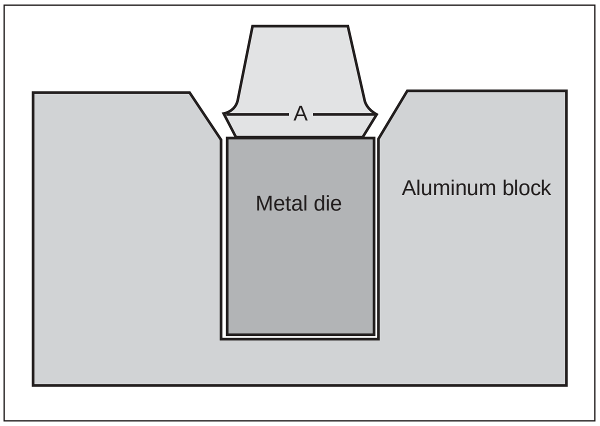

Fig 1 Metal die within recess; *A* = measured diameter.

Table 1 Impression Materials

Brand name	Type	Viscosity
Express, 3M	Polyvinyl siloxane	Putty, light
Examix, GC	Polyvinyl siloxane	Putty, light
Elite, Elite	Polyvinyl siloxane	Putty, light
Permadyne, ESPE-Premier	Polyether	Heavy, light
Permlastic, Kerr/Sybron	Polysulfide	Heavy, light

areas, usually present apical to the finish line of a prepared tooth.

The purpose of this study was to examine the effect of various gingival sulcular widths, in the presence of an undercut, on the linear accuracy of dies poured from impressions made with different impression materials. It was hypothesized that, in the presence of an undercut, the deformation of an impression would increase in an inverted ratio to sulcular width, and that impression materials with lower strain tolerance may have greater deformation.

Materials and Methods

An aluminum block was prepared with a cylindric recess of 9 mm in diameter in its center. The rim of the recess was prepared diagonally, at an angle of 102 degrees to the block surface, to create a 2-mm-long slope (Fig 1). Six metal dies were prepared to accurately fit the cylindric part of the recess. The dies were machined to simulate a tooth with a chamfer preparation. All dies were prepared similarly:

1. The angle between the axial and occlusal walls was 102 degrees.
2. Apical to the finish line, the dies converged with a 78-degree angle (parallel to the slope).
3. The length of the converged wall was 1 mm, half that of the slope, creating a "sulcus" 1-mm deep around the preparation and thus defining an emergence profile.

The dies differed only in their diameter (about 9 mm), thus creating six varying "sulcular" widths (0.10, 0.15, 0.20, 0.25, 0.30, and 0.40 mm).

Impression trays were fabricated using autopolymerizing acrylic resin (GC), with silicone putty (Elite) adapted as a tray spacer around the dies. Undercuts were prepared on the inner side of the trays, and venting holes were drilled with a No. 8 bur (Thomas). The trays were allowed to polymerize for at least 24 hours before making the impressions. Impressions were made using five different impression materials: three brands of polyvinyl siloxane, one polyether, and one polysulfide (Table 1). Each impression material was used to make 10 impressions of each of the six metal dies; thus, 60 impressions were made with each brand.

A double-mix impression technique was employed. According to Johnson and Craig,[6] the double-mix (one-step) impression technique gives the best recovery from undercuts when measured horizontally, compared with single-mix and putty-wash (two-step) techniques. Others[7,8] found no statistically or clinically significant differences between the putty-wash one- and two-step techniques. Nissan et al[9] found the polyvinyl siloxane two-step putty-wash technique with 2-mm relief to be more accurate than a one-step putty-wash technique for measuring interabutment distance and abutment height. However, in the present study, the die diameter at the finish line was measured; according to Hung et al[7] and Idris et al,[8] that parameter is not significantly influenced by technique.

The prepared resin trays were coated with the suitable adhesives and allowed to dry for 10 minutes. Low-viscosity impression material was injected into the sulcus and around the abutment using an elastomer syringe (ESPE Fabrik Pharmazeuticher Praparate), while high-viscosity material/putty was inserted into the tray and seated over the die with light pressure. The materials were allowed to set at a room temperature of 23°C for 10 minutes, then separated from the model. The impressions were rinsed with soapy water to lower surface tension and poured with type IV stone (Silky-Rock, Whip Mix) with a powder:water ratio of 100 g:22 mL. The stone was mixed under vacuum (Degussa).

The diameter of every specimen was measured four times using a Toolmaker's Microscope (model TM 300, Mitutoyo), and the mean diameter was considered to

Table 2 Mean (Standard Deviation) Distortion of Stone Die Diameters for Varying Sulcular Widths§

Distortion (%)	Express	Examix	Elite	Permadyne	Permlastic
P_1	0.89 (0.19)	0.43 (0.31)	0.72 (0.16)	0.45 (0.33)	0.58 (0.32)
P_2	0.37 (0.17)	0.08 (0.26)	0.26 (0.10)	0.27† (0.13)	0.11 (0.28)
P_3	0.25 (0.12)	0.05 (0.44)	0.13 (0.12)	0.14 (0.38)	0.18 (0.13)
P_4	0.39 (0.12)	0.08 (0.19)	0.23 (0.03)	0.01 (0.21)	0.19 (0.22)
P_5‡	0.50 (0.11)	0.22† (0.25)	0.45 (0.09)	0.23† (0.29)	0.07 (0.43)
P_6	0.31 (0.11)	0.12 (0.29)	0.35 (0.10)	−0.78 (0.97)	0.21 (0.34)

§P_n = % distortion for W_n (see Materials and Methods section). Unbalanced repeated measures models with structured covariance matrices (Wald test of significance of fixed effect and covariated) between P_1 (% distortion of W_1) and P_2 to P_6 (% distortion of W_2 to W_6) were carried out for each tested material. All results were statistically significant, except those marked † ($P > .05$).
ΠOne-way ANOVA for P_n suitable for W_n for each of the five materials. All results were statistically significant, except those marked ‡ ($P > .05$).

be the reading for that specimen. The accuracy of the impressions was indirectly assessed by comparing the diameters of the metal and respective stone dies at the level of the finish line. The distortion (%) of each die was calculated according to the formula:

$$\frac{(\text{Metal die diameter} - \text{Stone die diameter}) \times 100}{\text{Metal die diameter}}$$

The experimental error was determined by measuring the diameter of the same stone die 10 times and calculating the coefficient of variation:

$$\frac{\text{Standard deviation} \times 100}{\text{Mean}}$$

Unbalanced repeated measures models with structured covariance matrices tests were used to examine the differences between P_1, the percentage distortion of each material in the narrowest sulcular width (W_1), and the other percentage distortions of each material P_2 to P_6 at the wider sulcular widths (W_2 to W_6). The differences were tested within the same material because W_n is a repeated variant that is not balanced. Furthermore, the difference between P_1 and P_n is obvious, whereas the differences among the other P_n values are not; therefore, they were not tested.

One-way analysis of variance (ANOVA) was carried out to see if there was a statistically significant difference among the materials for the same W_n at a significance level of 95%. When statistically significant differences were found, a Bonferroni post hoc test was used for comparison of individual means.

Results

All materials behaved similarly: At the narrowest sulcular width (0.10 mm), the distortion was considerably larger than at the wider sulci, ranging from 0.43% to 0.89% (Table 2). The experimental error (coefficient of variation) was 0.1%.

Examix, Elite, Permlastic, and Express had statistically significant differences between P_1 and the other P_n values ($P < .05$). Permadyne showed a difference between P_1 and the other P_n values, except for P_2 and P_5. P_6 had a negative value.

The P_n suitable for W_n for each of the five materials was investigated by one-way ANOVA. Statistically significant differences ($P < .05$) were found, except for P_5 suitable for W_5 (0.30-mm sulcular width).

The Bonferroni post hoc test did not reveal statistically significant differences at P_2 or P_3, whereas ANOVA did find such differences. The Bonferroni test was not sensitive enough to reveal the differences within the groups because of the small sample size. The Bonferroni post hoc test did show that Express significantly differed from Examix and Permadyne at P_1 ($P <$ .05). The metal die diameter at W_1 was 9.635 mm. Express showed a mean deformation of 0.89% (ie, 86 μm), and Examix and Permadyne showed mean deformation of 41 μm and 43 μm, respectively. The Bonferroni post hoc test also showed statistically significant differences between Express and Examix, Express and Elite, and Express and Permadyne at P_4, Express having a 37-μm deformation and the others having 7 μm, 22 μm, and 1 μm, respectively.

Discussion

This study demonstrated the distortion of stone dies made from impressions of metal dies with varying sulcular widths, a fixed sulcular depth, and an undercut. The impression materials used were three polyvinyl siloxanes, a polyether, and a polysulfide.

The distortion ranged from 0.01% to 0.89%. At the narrowest sulcular width (0.10 mm), the distortion was considerably larger than at the wider sulci. The American Dental Association[10] defines the dimensional change allowed for nonaqueous, elastomeric impression materials as 2.5%, using a compressive test. The present study examined dimensional changes using different forces not of a compressive nature. Thus, the results cannot be compared to the aforementioned specification. To our knowledge, no other standard has been fixed for distortion of impression materials during impression making. Hondrum[11] took an arbitrary estimation of 0.4% deformation to be the significant deformation limit. He did not try to define a precise point, but rather to compare the tested materials. Nevertheless, judging by this estimate, the distortion at a sulcular width of 0.10 mm was significant.

The metal die diameter in the 0.10-mm sulcus model was 9.635 mm, and the distortion of the stone dies at that sulcular width ranged from 0.43% to 0.89%, giving a distortion of 41 to 86 μm in diameter (the distortion may or may not be symmetric). This experiment examined the inaccuracies at the early stages of crown fabrication. Further inaccuracies will be added in the consecutive processes of crown casting,[12] electroforming[13] or milling,[14] ceramic firing,[13] etc. In the literature, there is no agreement on the clinically tolerable gap between the crown and tooth; it may vary between 31 and 119 μm.[13,15–17] Thus, it may be concluded that a distortion of 41 to 86 μm at this early stage has clinical significance.

The distortion of the tested materials at widths W_2 to W_6 was significantly different than at W_1 ($P < .05$). In the wider sulci, the distortion was about 0.20% in most cases, causing a distortion of about 20 μm of the stone die diameter. Permadyne (a polyether) demonstrated exceptional distortion, with a negative value, at a sulcular width of 0.40 mm (W_6). This result was most likely due to a mistake during sample preparation. Within the limitations of this study, Examix (polyvinyl siloxane), Permlastic (polysulfide), and Permadyne (polyether) gave the most accurate dies for sulci wider than 0.15 mm.

Laufer et al[18] showed that when the sulcular width is 0.18 mm or less, it is impossible to predictably obtain good impressions because of tearing and distortion of the thin impression margins. Those authors examined the distortion of the impression margins at the bottom of the sulcus. The present study investigated the distortion at the finish line itself, 1 mm coronal to the bottom of the simulated sulcus. Although tears and distortion occurred in sulci of 0.10 mm, they did not always affect the finish line.

All of the impression materials gave predictable results in sulci of 0.15 mm and wider and had a marginal clinical acceptability in sulci of 0.10 mm or less (Express having a greater deformation for all sulcular widths). Statistically significant differences among the materials for the same sulcular width were found, except for the 0.30-mm width ($P > .05$).

Previous studies[6–8] investigated addition silicones for differences in accuracy between one- and two-step techniques. They examined the differences in duplicated undercut dies and found no significant difference or clinical significance. The present study used the one-step technique to check the accuracy of addition silicones as well as other types of impression materials when duplicating undercut dies. Polysulfides, having the highest permanent set, were expected to show the highest distortion among the materials tested. The results showed a behavior similar to that of the other impression materials in the study. This could have happened because the strain exerted on the impression when it was separated from the model was smaller than that needed to create a clinically significant permanent deformation in the polysulfide.

Conclusions

The present study investigated three polyvinyl siloxanes (Examix, Elite, and Express), one polyether (Permadyne), and one polysulfide (Permlastic). Under the conditions of the study, the materials' behavior could not be related to their chemical group. In clinical situations mimicked by this model, as long as sulcular width is 0.15 mm or greater, all three groups of materials are suitable for obtaining clinically acceptable impressions.

1. It was not always possible to predictably obtain accurate impressions in a sulcus of 0.10-mm width in the presence of an undercut.
2. All impression materials gave clinically acceptable results in sulci 0.15 mm and wider in the presence of an undercut. Express showed greater deformation than the others.
3. Under the conditions of this study, the physical properties of impression materials could not be predicted accurately based on their chemical group.

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Literature Abstract

The effectiveness of auxiliary features on a tooth preparation with inadequate resistance form

This study evaluated the efficacy of various auxiliary preparation features on the resistance form of crowns with reduced axial walls and excessive total occlusal convergence (TOC). A crown preparation with 20-degree TOC, 2.5 mm of occlusocervical dimension, and a shoulder finish line was made on an Ivorine tooth (occlusocervical/faciolingual dimension ratio below 0.4). The crown preparation was later modified to include mesiodistal grooves, mesiodistal boxes, buccolingual grooves, occlusal inclined planes, an occlusal isthmus, and reduced TOC in the axial wall from 20 to 8 degrees TOC in the cervical 1.5 mm of the axial wall. The grooves and boxes were placed into the tooth with the same 20-degree TOC as the axial walls. Standardized complete metal crowns were fabricated for all specimens. The metal crowns were cemented on metal dies with resin-modified glass-ionomer cement. A strain gauge was placed at the mid-lingual cervical area of each crown preparation margin to detect the force that initiates micromovement (2 µm). The resistance of each specimen was evaluated when a 45-degree force was applied to the long axis from a lingual to buccal direction. The maximum loads during crown dislodgment (tensile stress at the mid-lingual cervical area) were measured using a universal testing machine. The control group consisted of 10 dies, with the original crown preparation. Data were analyzed using the Mann-Whitney U test. The results indicated that the only auxiliary feature crown modification that improved resistance form was the reduced TOC in the cervical half of the axial wall (from 20 to 8 degrees). All the other tested auxiliary features were ineffective at increasing the resistance to dislodgement when the original tooth preparation has poor resistance form. The authors concluded that incorporation of auxiliary retentive features into a compromised tooth preparation was not effective when these retentive features possessed the same 20-degree TOC as the prepared axial walls. This is an enlightening study that evaluated scientifically the efficacy of auxiliary tooth preparation elements for crowns.

Proussaefs P, et al. *J Prosthet Dent* 2004;91:33–41. **References:** 29. **Reprints:** Dr Periklis Proussaefs, School of Dentistry/Loma Linda University, Center for Prosthodontics and Implant Dentistry, Loma Linda, CA 92350. e-mail: pproussaef@hotmail.com—*Ansgar C. Cheng, Singapore*