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Penetration ability of various elastomeric impression materials using a gingival sulcus model

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Abstract

This study aims to compare the penetration ability of elastomer impression materials in a three-dimensional gingival sulcus model. Four types of elastomer (polyether, polysulfide, addition curing silicone and vinylpolyethersiloxane) were tested using models with three sulcular widths (0.2 mm, 0.1 mm and 0.05 mm). Six impressions were taken for each width with one material type. They were measured by stereomicroscope (Olympus SZ61) and interpreted by image analysis software (Image-Pro Plus). A two-way ANOVA and Dunnette T3 test were performed with the level of significance (P-value) set at $P < 0.05$. The results of this study showed no statistically significant differences among four elastomers for a 0.2 mm and 0.1 mm gingival sulcus. For a 0.05 mm sulcus width, polysulfide demonstrated the best penetration ability and flowability into the sulcus. This was statistically higher than additional curing silicone and vinylpolyethersiloxane. In conclusion, our three-dimensional gingival model revealed the penetration characteristics of elastomeric impression materials. In clinical application, using polyether and polysulfide materials for narrow sulcus width may yield good clinical results for restoration.

Keywords: *elastomer; elastomeric impression materials; gingival sulcus model; narrow sulcus, penetration ability; vinylpolyethersiloxane.*

1. Introduction

Impression materials play an important role in the process of restoration fabrication. They transfer the details of the tooth structure required for laboratory work. Impression materials are essential when constructing crowns or bridges. High quality dental impressions are essential for successful fixed prosthodontic work. Dental impressions should be able to provide accuracy, good dimensional stability, elastic recovery, biocompatibility and non-toxicity to the oral cavity (Craig, 1988; Hamalian, Nasr, & Chidiac, 2011; Ferro et al., 2017). These properties are the ideal properties. Other desirable characteristics include flowability and hydrophilicity especially when the margin is subgingival.

There are various kinds of impression material available in the market. Elastomeric materials are commonly used for crown fabrication, such as polysulfide, additional silicone or polyvinylsiloxane and polyether. Each elastomeric type can be used in several conditions, depending on the type of restoration, material properties and patient's condition. Although elastomeric materials are well-known for replicating crowns and bridges, one of the major challenges for impression is the subgingival margin of tooth preparations due to factors such as salivation, bleeding or sulcular fluid. The aforementioned factors could also lead to an inaccurate impression and marginal discrepancy, which ultimately increase the risk of secondary caries and affect periodontal health. To avoid these problems, the key success factors, consisting of a definite finishing line, a suitable sulcus opening and a dry environment, are required. Nevertheless, qualified impression material properties and suitable impression technique are also vital (Mandikos, 1998). Polysulfide was the first ever elastomeric impression material. It had been used for several decades because of its good detailed reproduction and dimensional stability. However, its usage decreased over time because it was found to stain clothes, has an unpleasant odor and a strong bitter taste. Later, addition curing silicone, which is also known as polyvinylsiloxane, emerged in the market. Polyvinylsiloxane has high accuracy, good dimensional stability, good elastic properties, high tear strength and excellent flow. However, it is hydrophobic which makes it difficult to capture the details subgingivally with high moisture (Council on Dental Materials and Devices, 1977). At present, polyether, which is hydrophilic and suitable for capturing the subgingival details, is widely used. This type of material hardens when it is fully set. Therefore, it is difficult to remove the impression in the area of undercuts both intra- and extra-orally (Lawson, Cakir, Ramp, & Burgess, 2011). A recently developed material called "vinylsiloxanether" combines polyether with additional silicone. This new product is hydrophilic, is superior for detail reproduction and better elasticity after fully set. Hence, it is easier to remove when the undercut is presented (Shetty, Bhandari, & Mehta, 2014; Stober, Johnson, & Schmitter, 2010)

To make a proper impression, abutment condition and gingival management are as important as the impression itself. The restoration margin position relative to the gingival margin is a significant factor to control gingival health (Aimjirakul, 2009). Supraginigval margins are desirable for gingival health unless supragingival cannot be obtained. Hence, the margin needs to be subgingival. Subgingival margin placement is required for several reasons such as to cover old restorations or decay, to increase the length of the tooth structure and to enhance aesthetics in anterior teeth. When tooth preparation produces a subgingival finishing line, it is rather difficult to take an impression because of its technical sensitivity including inaccessibility, fluid control of blood or gingival fluid and the width of the gingival sulcus. Aimjirakul, Masuda, Takahashi and Misura (2003) studied the prevalence of finishing line location of prepared teeth and revealed that 80.0% of the 60 post and core preparations involved the equi-gingival or subgingival finishing line. Furthermore, the extension of impressions should be more than 0.3 mm to achieve good marginal trimming. Therefore, the management of subgingival restorative margins is a crucial factor in achieving excellent restoration.

This leads to the purpose of this research, which is to compare the penetration ability of different impression materials into the gingival sulcus in order to determine the most suitable impression material for subgingival restorative margin.

2. Objectives

The objective of this study is to measure the penetration depth of various elastomeric impression materials into different sulcular widths by using a gingival sulcus model.

3. Materials and methods

3.1 Elastomeric impression materials

Four elastomeric impression materials of both medium and light consistency were studied (Table 1). Six impressions were made from each impression material for the three different sulcular width groups. The total number of impression specimens was 72 samples.

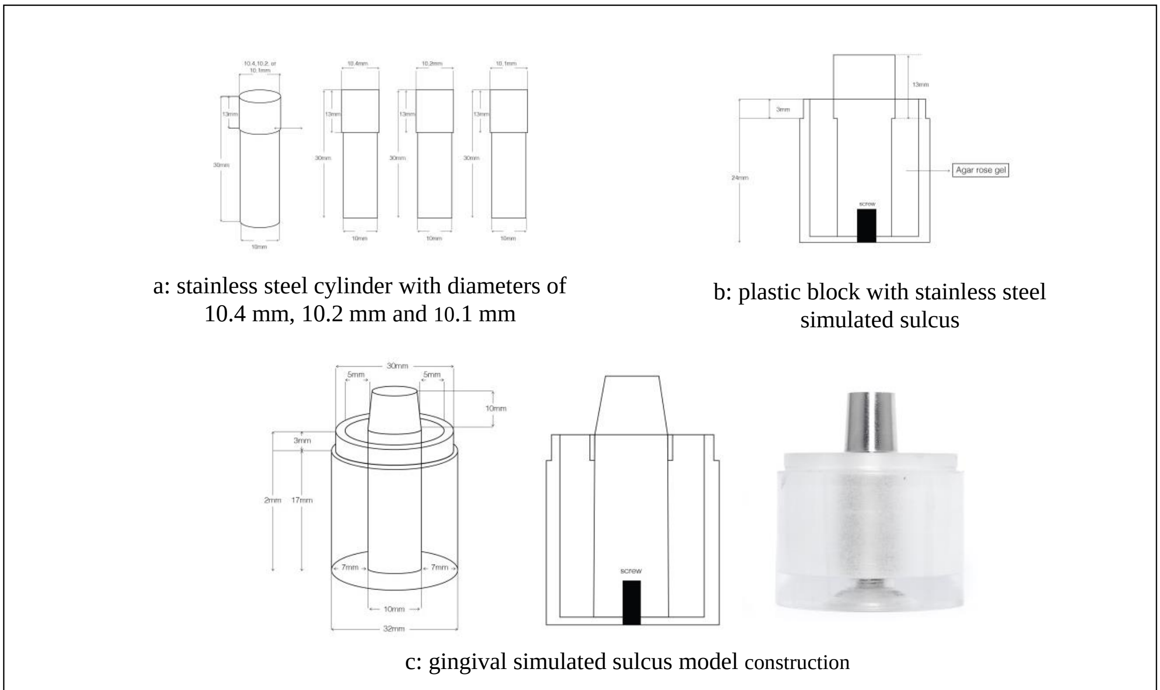
3.2 Gingival simulated sulcus model construction

The gingival sulcus model uses 3 sizes of stainless-steel cylinder with diameters of 10.4 mm, 10.2 mm and 10.1 mm. The diameter will simulate the gingival sulcus depth of 0.2, 0.1 and 0.05 respectively (Figure 1a). First, the simulated sulcus stainless-steel cylinder with diameters of 10.4, 10.2 and 10.1 mm are screwed into the plastic block. 1% agarose gel (Agarose S, Nippongene) is poured into the bottom of the plastic block in an incubator (27 ± 2º c and 100% relative humidity). The agar is then left to set for 20 minutes (Figure 1b).

The screw at the bottom of the block is loosened and the stainless-steel simulated sulcus is gently separated from the plastic block to construct simulated gingival tissue with 0.2, 0.1, and 0.05 mm sulcus widths. A simulating tooth (stainless-steel cylinder with 0.5 mm chamfer finishing line and slight convergence) is inserted into the simulated gingival sulcus to construct a 3 mm depth gingival sulcus of three different widths (0.2, 0.1 and 0.05 mm), with one wall representing the gingival and the stainless-steel cylinder representing the tooth (Figure 1c).

Table 1 Elastomeric impression materials tested

Type of material	Brand name	Lot No.
Polyether	Impregum™ Penta Soft, 3M ESPE	5486491
	Impregum™ Garant L DuoSoft, 3M ESPE	5459727
Additional curing silicone	Provil® novo Medium, Heraesus Kulzer	K010023
	Provil® novo Light, Heraesus Kulzer	K010024
Polysulfide	Permlastic™ Regular, Kerr	7127890
	Permlastic™ Light Bodied, Kerr	7190730
Vinylsiloxanether	Identium® Medium, Kettenbach	180221
	Identium® Light, Kettenbach	180801058



a: stainless steel cylinder with diameters of 10.4 mm, 10.2 mm and 10.1 mm

b: plastic block with stainless steel simulated sulcus

c: gingival simulated sulcus model construction

Figures 1 1a Stainless steel cylinder with diameters of 10.4 mm, 10.2 mm and 10.1 mm; **1b** Plastic block with stainless steel simulated sulcus and agar rose gel, and **1c Gingival** simulated sulcus model construction with one wall representing the gingival and the stainless-steel cylinder representing the tooth

3.3 Impression materials and technique

All impressions were taken with the single step syringe-tray technique by inserting the light body circumferentially into the gingival sulcus. The medium body was placed in the perforated stainless-steel tray and immediately seated with light pressure (Figure 2). This process was conducted in the incubator at 27 ± 2 ºc and 100% humidity by one operator only. A total of 72 impressions were made from the simulated models, with six impressions of each material for the three sulcular width groups. The impressions were removed from the model and stored at room temperature for 30 minutes, following the recommended setting time by the manufacturer, before the impression extensions were measured.

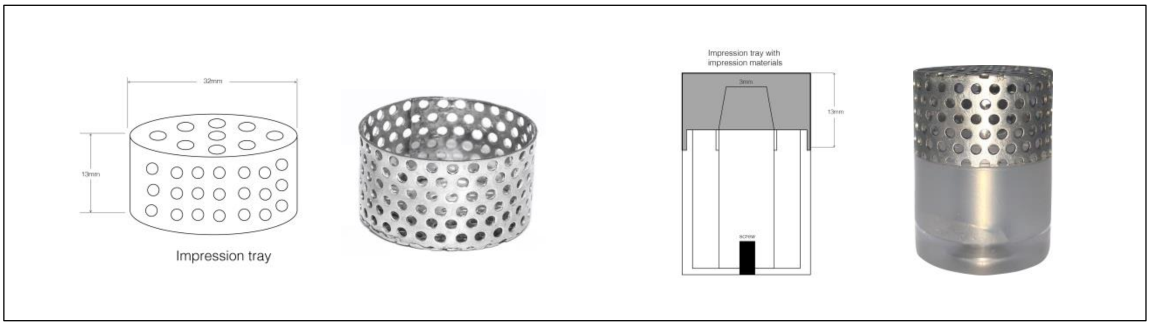


Figure 2 Perforated impression tray and a demonstration of the impression of the gingival sulcus using a perforated impression tray

3.4 Measurement of the penetration depth of the impression material

The extensions of the impressions that penetrated the stimulated sulcus were measured using four reference marks (Figure 3a). The height of each extension was determined by using a stereo microscope (Olympus SZ61 stereomicroscope, Japan) and Image-Pro Plus image analysis software (Media Cybernetics, Inc., USA) (Figure 3b).

Figures 3 3a (Left) The extension of the impressions that penetrated the stimulated sulcus ; **3b (Right)** Penetration of the impression material into the gingival sulcus obtained from Image-Pro Plus image analysis software (Media Cybernetics, Inc., USA)

3.5 Statistical analysis

The data of this study were analyzed by using two-way ANOVA analysis of variance for group comparison, and multiple comparison test analysis of variance for individual group comparisons, using SPSS version 20.0 (IBM SPSS Statistics for Windows, version 20.0, NY, USA). The level of statistical significance (P-value) was set at $P \leq 0.05$.

4. Results

The mean average heights and the standard deviations are presented in Table 2. Two-way ANOVA revealed significant differences between the impression materials, sulcular widths, and their interactions ($P < 0.05$). Dunnett T3 analysis showed that the penetration ability for the various types of impression material was significantly different for the four materials, which were Provil novo - Permlastic, Provil novo - Impregum, Permlastic - Identium and Impregum - Identium.

For the various sulcular widths, all of the paired comparisons were different. These differences were statistically significant. When considering the three sulcus depths, no statistically significant differences were found for any of the impression materials. Regarding the 0.2 mm group, Impregum had the best reproducibility with an average extension height higher than that of Permlastic, Identium and Provil novo respectively.

Table 2 Mean values and standard deviations of impression extension (mm)

Sulcular width (mm.)	Polyether (Impregum™, 3M ESPE)		Additional curing silicone (Provil® novo, Heraeus Kulzer)		Polysulfide (Permlastic™, Kerr)		Vinylsiloxanether (Identium®, Kettenbach)	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
0.2 mm	0.83[a]	0.20	0.78[a]	0.23	0.81[a]	0.58	0.79[a]	0.03
0.1 mm	0.64[b]	0.11	0.49[b]	0.11	0.57[b]	0.10	0.51[b]	0.05
0.05 mm	0.41[c]	0.58	0.17[d]	0.21	0.42[c]	0.40	0.27[e]	0.03

*Groups with the same superscripted letter indicated no significant differences between impression materials at $P < 0.05$. SD = standard deviation

For the 0.1 mm group, Impregum was also the best at reproducing the extension height, followed by Permlastic, Identium and Provil, respectively. For the 0.05 mm sulcus width, Permlastic had the best penetration ability material closely followed by Impregum and Identium, whilst Provil Novo offered the poorest mean extension height. However, the differences between Permlastic and Impregum material were not statistically significant (P value > 0.05), but when compared with Identium and Provil, was statistically superior.

Impregum had a greater extension ability, compared with the other three materials, especially for the 0.2 and 0.1 mm sulcus widths, whereas Permlastic was the best for the 0.5 mm width (Figure 4).

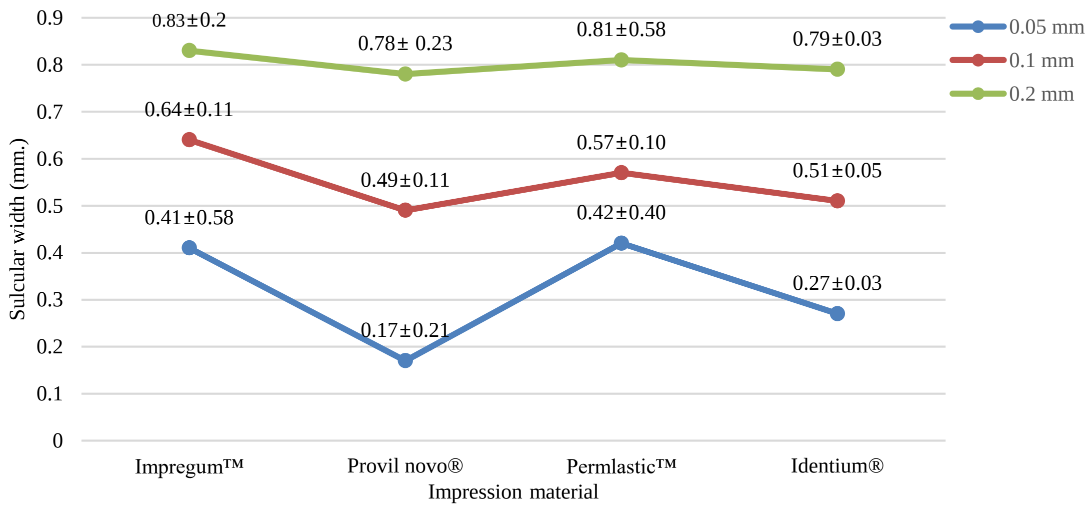


Figure 4 Mean values and Standard deviations of the Impression Extension (mm)

5. Discussion

Each type of impression material differs in their structure and components, which leads to different penetration abilities. This study, as well as previous studies, showed that polyether had the highest penetration ability under the experimental conditions while additional curing silicone had the lowest penetration ability.

This study determined the penetration ability with a single impression technique. However, the flowability rate of an impression material does not depend only on this property. Other vital factors include tear resistance, viscosity, hydrophilicity, good contact angle and various impression techniques (Donovan & Chee, 2004; Hamalian et al., 2011). According to a study by Herfort, Gerberich, Macosko and Goodkind (1978), polyether and vinylpolyethersiloxane demonstrated higher tear strength than silicones, resulting in better flowability into the gingival sulcus. Many publications analyzing the contact angle of the elastomer impression material stated that polyether and vinylpolyethersiloxane had smaller contact angles than silicone (Kugel, Klettke, Goldberg, Benchimol, & Sharma, 2007; Menees, Radhakrishnan, Ramp, Burgess & Lawson, 2015; Pratten & Craig, 1989). This indicates greater flowability and adaptability when contacting the tooth surface. Many previous studies reported that the chemical structure of polyether and vinylpolyethersiloxane were hydrophilic, whereas silicone was hydrophobic with a surrounding hydrocarbon polymer that resists water (Rupp, Axmann, Jacobi, Groten, & Geis-Gerstorfer, 2005; Van Krevelen & Te Nijenhuis, 2009). To counteract this hydrophobic characteristic, surfactant was added, but polyether was still naturally better. Therefore, additional silicone was shown to have the least flowability into the gingival sulcus, which was in accordance to the result of the present study (Ciesco, Malone, Sandrik, & Mazur, 1981). Further studies under different laboratory conditions are suggested when selecting the most appropriate impression material in a clinical setting

In addition to the impression material's properties, the width of the gingival sulcus also affects the penetration ability. With reference to a study by Laufer, Baharav, and Cardash (1994) and Laufer, Baharav, Ganor, and Cardash (1996), the critical sulcular width for the penetration of impression material should be 0.2 mm, with rapid closure of the sulcus to less than 0.2 mm within 40 seconds of removing the retraction cord. We applied these values in this study by using three different sulcus widths; 0.2 mm, 0.1 mm and 0.05 mm. The results indicated diverse penetration ability for different sulcular widths. For 0.2 mm and 0.1 mm widths, Impregum had the highest penetration. However, the differences found between all of the impression materials were not statistically significant. This was in accord with previous research by Aimjirakul et al., 2003. Regarding the sulcular width of 0.05 mm, all materials were not able to capture the details well enough and their differences were statistically significant. Surflex F polysulfide was superior to silicones under the same conditions since it had greater tear strength and permanent set. It was expected to be deformed rather than torn, demonstrating a complete set but a distorted impression. A low viscosity material can penetrate well in an abutment without undercut. The specimens used in this study had no undercut and were hydrophillic, resulting in high penetration values. The results confirmed the conclusion of Craig 's study that Permlastic penetrated better than Impregum in a sulcus with 0.1 mm width (Craig, Urquiola, & Liu, 1990).

In contrast, polyether can be stiff when fully set, making it difficult to remove, especially in areas with undercuts or narrow sulcus. Breakages of both the impression and the dental cast can occur as a consequence. This supports the result of the study that with a 0.05 mm sulcus, polyether had lower penetrative ability than polysulfide, but the difference was not statistically significant. In the field of fixed prosthetic dentistry, polysulfide is not widely used for dental crown fabrication due to its low dimensional stability, long setting time, unpleasant odor, strong bitter taste, staining, and handling difficultly (Craig, 1988; Ferro et al., 2017).

In a narrow sulcus, it is difficult for impression material to penetrate and achieve a perfect die margin due to insufficient space. However, previous study recommended that the penetration ability of an impression material should be more than 0.3 mm depth in order to achieve a good marginal trimming (Aimjirakul, Masuda, Takahashi & Miura, 2002). In this study, it was found that only Impregum and Surflex F achieved an extension depth of more than 0.3 mm with a sulcus width of 0.05 mm. Even though there was a wide range of standard variation values, the results did not differ from previous studies (Craig et al., 1990; Aimjirakul et al., 2002). This could be clinically applicable in cases of a narrow sulcus as polyether and polysulfide are clinically acceptable for fabricating restoration.

The American Dental Association has no set regulations on how to measure the penetration ability for non-aqueous, elastomeric dental impression materials. Several models have been created by researchers, to test this ability of elastomeric material. The present study has developed and utilized previous models such as the shark fin test, which is a 2-dimensional linear model, constructed in a solid condition unlike the oral cavity (Balkenhol, Wöstmann, Kanehira, & Finger, 2007; Finger, Kurokawa, Takahashi, & Komatsu, 2008). This study was designed as a new model in an attempt to simulate the clinical situation of tooth preparation with agar material on one wall representing the gingiva. The opposing side is a stainless-steel cylinder representing the tooth with a 0.5 mm chamfer finishing line and slight convergence. The space in between represents the gingival sulcus. Although the simulation sulcus innovative model does not completely mimic the condition of the oral cavity, it is considered suitable to compare the impression materials' penetration ability under the given moisture and elasticity conditions.

From a clinical point of view, it is difficult to fabricate a good impression of a narrow gingival sulcus when not used with a retraction cord or appropriate impression material. This in vitro study demonstrated that polyether and polysulfide had high ability to penetrate in a narrow sulcus. The results may be beneficial in clinical situations which require multiple preparations when a retraction cord cannot be removed in time and where a subgingival margin is present. However, it is greatly important to note that a proper impression should always be checked regarding the three compositions, which are the impression itself, the abutment condition and gingival management.

6. Conclusion

The following conclusions can be drawn from this research:

1. Different elastomeric impression materials have the ability to penetrate into the 3-dimensional gingival model differently, depending on the width of the gingival sulcus.

2. The penetration ability of different elastomeric impression materials became greater with wider sulcus.

3. For gingival width less than 0.05 mm, polyether and polysulfide were found to be suitable for obtaining clinically acceptable impressions.

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