

# Influence of Different Finish Line Types on the Penetration Properties of Elastomeric Impression Materials

## Keywords

Silicone Elastomers  
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## ABSTRACT

*Introduction:* The objective of this study was to determine the penetration ability of elastomeric impression materials affected by abutment finish line configurations with a simulated gingival sulcus model. *Methods:* The gingival sulcus model was simulated using agarose gel and milled abutment models. Twenty impressions of each finish line (feather-edge, mini-chamfer, chamfer, heavy chamfer, and radial shoulder) were made. Four elastomeric impression materials were used for the two-step double-mixed, double-impression technique, consisting of polysulfide, polyvinylsiloxane, polyether, and vinylsiloxanether (N=120). The extension of impression that flowed into the simulated gingival crevices was measured under a stereomicroscope by using image analysis software. *Results:* Two-way analysis of variance revealed statistically significant main effects and an interaction between finish line type and impression material type ( $p<0.05$ ). The radial shoulder showed significantly greater penetration than the other finish lines for polyvinylsiloxane, polyether, and vinylsiloxanether ( $p<0.05$ ). *Conclusions:* The type of finish line influences the ability of elastomeric impression materials to penetrate within a simulated gingival sulcus model. The penetration ability of elastomers tends to increase due to the increasing width of the finish line. Among all the materials, polyether has the greatest potential to penetrate through the narrow gingival sulcus.

## INTRODUCTION

Rheological properties of elastomeric impression material play a role in capturing the fine details of the abutment tooth and gingival sulcus during impression-taking, to imprint the relationship between the soft tissues and tooth structure in the oral cavity for creating a precise model.<sup>1,2</sup> The role of impression-taking is to imprint the relationship between the soft tissues and tooth structure in the oral cavity to create an accurate a die or model. The smooth and continuous finish line should be captured by impression materials. In a semi-digital workflow, a clearly defined finish line on the stone model provides margin detection with a laboratory scanner to generate 3-dimensional stereolithography (STL) files of the dental model.<sup>3</sup> A subgingival margin condition, which is facilitated by an extensive defect owing to subgingival dental caries and defective restoration, presents a difficult clinical scenario for impression-taking in clinical practice, due to the deeper and narrower-in-width gingival sulcus.<sup>4</sup>

Allowing impression material to penetrate, simulate surface texture, and precisely identify the finish line requires gingival retraction to produce an appropriate gingival sulcus width of at least 0.2 mm.<sup>5</sup> Clinically, when insufficient retraction techniques are performed or when the impression-taking is delayed 20 seconds or more after the retraction cord has been removed, a gingival sulcus less than 0.05 mm in width could be observed.<sup>5</sup> Saliva, blood, and crevicular fluid are all challenging conditions for moisture control.<sup>4</sup> Impression-taking in case of subgingivally placed margins must include not only the area of preparation and finish line but also some unprepared tooth structure apically.<sup>1</sup> Whenever maintaining dry fields during the impression-taking process is not feasible, it could interrupt the polymerization of elastomeric impression material and lead to inadequate detail recording.<sup>6</sup> Incomplete recording and indistinguishable finish lines are often detected as visible flaws in impressions.<sup>1</sup> Hence, the ideal properties of elastomeric impression materials are critical factors for the accuracy of the impression, including good dimensional stability, accurate surface detail reproduction, high tear resistance, hydrophilicity, and favorable flowability.<sup>4,7</sup>

Elastomeric impression materials are the most common for fixed prostheses. Polysulfide (PS) can result in high tear strength, excellent wettability, and clear surface details, but unpleasant taste and odor, as well as high permanent deformation.<sup>8</sup> Polyvinylsiloxane (PVS) is hydrophobic, ensuring proper moisture control, which is essential in achieving a clinically acceptable impression, whereas polyether (PE) is hydrophilic and creates precise impressions even in moist environments.<sup>9</sup> Recently, a hybrid impression material which combined the strengths of PVS and PE has been developed and commercially available in 2009, namely vinylsiloxanether (VSE).<sup>10,11</sup> The hydrophilicity and flow properties of the VSE have the potential to improve material flow into the small gingival sulcus due to enhanced wettability in a moist environment.<sup>11</sup>

The finish line of a prepared abutment and confined areas of the gingival crevice should be achieved during impression-taking to replicate the accurate shape of the abutment and surrounding tissue.<sup>1</sup> The effect of finish line design has been previously investigated and correlated with the mechanical properties of restoration.<sup>12–14</sup> The properties of rheology, thixotropy, and wettability result in the ability to penetrate the gingival sulcus. In a prior investigation, it has been shown that the finish lines had an impact on the capacity of the impression material to penetrate within a simulated gingival sulcus model.<sup>15–18</sup> Specifically, the radial shoulder and deep chamfer configurations exhibit a wider width, leading to increased shear stress and decreased viscosity of the impression material compared to the chamfer finish line.<sup>18</sup>

Historically, the shark fin test apparatus has been utilized to illustrate the flow characteristics of impression materials.<sup>2,19,20</sup> However, the abutment and intraoral moisture level in the gingival sulcus could not be replicated using this testing procedure. Taking this into consideration, the aim of this investigation was to determine the penetration properties of

different elastomeric impression materials and the influence of finish line configurations under a simulated narrow gingival sulcus model. The primary null hypothesis of the study was that no significant differences would be detected in the penetration ability among different kinds of elastomeric impression materials. The secondary null hypothesis was that no significant differences would be detected in the penetration ability of all elastomeric impression materials influenced by different finish line types.

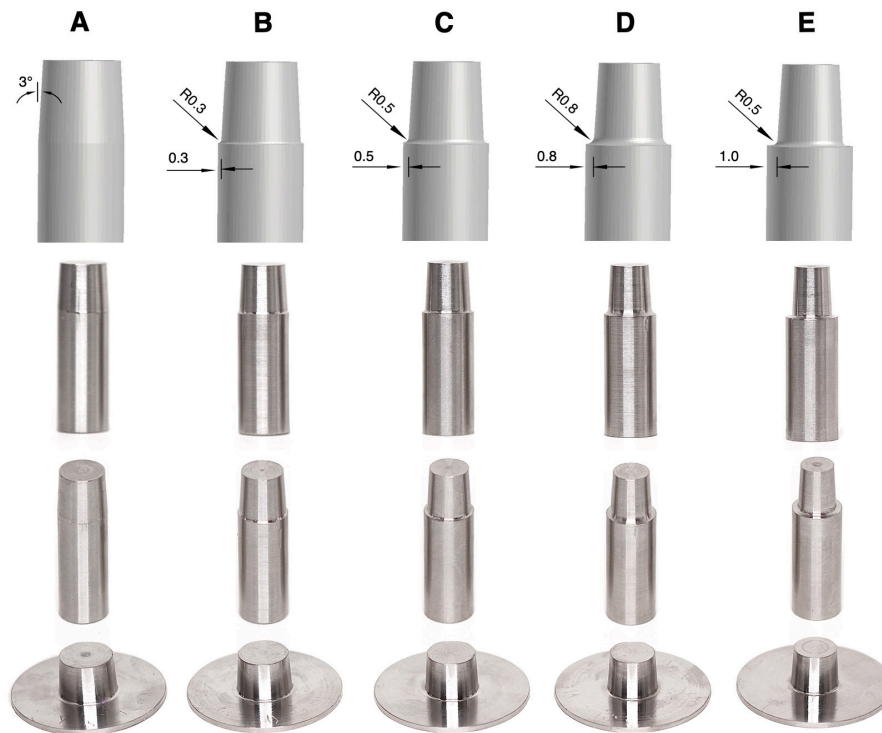
## MATERIALS AND METHODS

This laboratory experiment was performed under ISO 4823:2021; Dentistry - Elastomeric impression and bite registration materials.<sup>21</sup> The laboratory conditions were controlled under a relative humidity of 50(±10) percents and a temperature of 23(±2) °C. There were one hundred specimens in total. Twenty impressions of each finish line (feather-edge, mini-chamfer, chamfer, heavy chamfer, and radial shoulder) were made (n=20). Four elastomeric impression materials were used for two-step double-mixed, double-impression technique (n=5), consisting of PS (Permlastic®, Kerr, USA), PVS (Imprint™ 4, 3M ESPE, Germany), PE (Impregum™, 3M ESPE, Germany), and VSE (Identium®, Kettenbach, USA). For both PS's high and low viscosity, a standardized hand mixing method was performed to ensure repeatability and achieve good dispersion of all the components. The base and catalyst were proportioned by weight to control the mixing ratio. An automatic dynamic mixing machine was used for both high viscosity material and a static dispenser gun for low viscosity material for PVS, PE, and VSE.

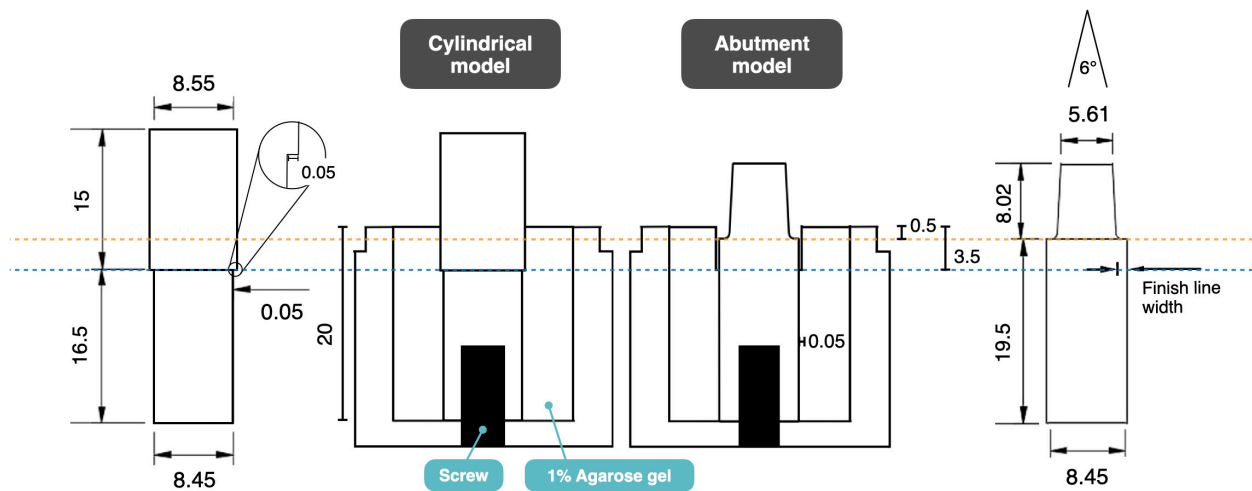
## MODEL CONSTRUCTION

All stainless-steel models were milled utilizing computer-assisted design software and computer numerical controlled (CNC) milling machines. Abutment models with five finish line configurations were designed, including a feather-edge finish line, a mini-chamfer finish line width of 0.3 mm, a chamfer finish line width of 0.5 mm, a heavy chamfer finish line width of 0.8 mm, and a radial shoulder finish line width of 1 mm (*Figure 1*). The total occlusal convergence abutment was 6 degrees, with an abutment diameter of 8.45 mm and a height of 8.02 mm. The model base had an 8.45 mm diameter and a 19.50 mm height. Stainless-steel cap as a block-out spacer for light viscosity materials was fabricated for the 5 types of finish line with a controlled thickness of 1 mm.

For the simulated gingival sulcus model, a cylindrical-shaped model was designed with a diameter of 8.55 mm and a height of 15 mm at the top portion, connected with 8.45 mm diameter and a height of 16.5 mm at the bottom portion of the model (*Figure 2*). The cylindrical-shaped model was screwed into the plastic block with four reference marks. 1% Agarose gel (LE agarose, Smart Science Co., Ltd, Thailand,) was filled into the chamber between cylindrical model and block in an incubator that controlled 35±1°C and 100% relative humidity for a 30-minute



**Figure 1:** Illustrations of five finish line designs, stainless-steel milled abutment model, cap spacer: (A) Feather-edge, (B) Mini-chamfer, (C) Chamfer, (D) Heavy chamfer, and (E) Radial shoulder.



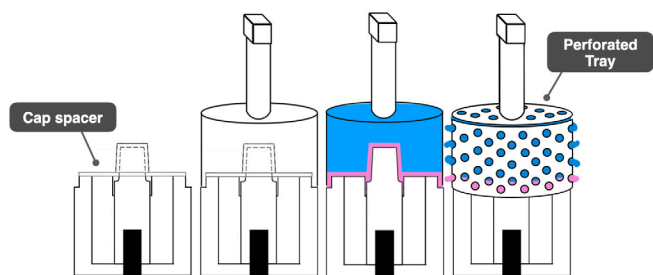
**Figure 2:** Simulated gingival sulcus model construction and the relationships among abutment models, cylindrical models, and agarose gel.

setting process. The screw at the base of the block was loosened, and then the cylindrical model was removed. Simulated abutment models with different finish line types were replaced in the model assembly. A gingival sulcus width of 0.05 mm and a depth of 3.5 mm were fabricated in the simulated gingival sulcus model. Simulated abutment and gingival models were single used immediately after construction.

### PENETRATION ABILITY TESTING

A two-step double-mixed, double-impression technique was performed. The heavy body was used and waited until completed set, as instructed by the manufacturer, followed by the light body. The thickness of the light body was controlled using

stainless steel cap-covered abutment models as the relieving spacer with a thickness of 1 mm (Figures 3 and 4). Impression material was injected into a milled perforated tray by the mixing tip, which was continuously submerged in the impression material in order to avoid bubble formation. Tray insertion was performed, and the light seating pressure of the tray was controlled with a universal testing machine at a cross-head speed of 500 mm/min. One hundred impressions, which were composed of twenty impressions of each finish line type, were created. Thereafter, they were divided into four groups of elastomeric impression material: PS, PVS, PE, and VSE. Prior to measuring an extension of the impression, the PVS, PE, and VSE impressions were left at room temperature for 24 hours, while the PS impressions were left for 30 minutes.



**Figure 3:** Assembly of the abutment model, plastic block, cap spacer, and perforated tray for the two-step impression technique.



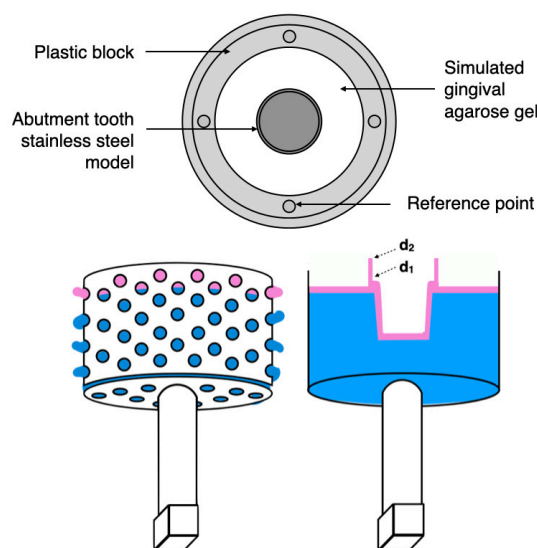
**Figure 4:** Milled abutment model, cap spacer, and perforated tray. (A) Simulated abutment in plastic block (B) Using cap models covered abutment model as the relieving spacer (C) The abutment model, plastic block, cap spacer, and perforated tray were assembled

The creeping of the flowed light body into the simulated gingival crevices, which represents penetration ability, was measured at four reference points at the margin of the plastic block. An impression sample is mounted on a plane-leveling stage to ensure that the specimen under inspection is completely fixed. A single examiner performs all readings. For each reference point, three measurements were conducted. The distance between the point at the finish line ( $d_1$ ) and the endpoint of the impression into a simulated sulcus ( $d_2$ ) was measured at the border under a stereomicroscope by using image analysis software with the precision level of the third decimal place at 10X magnification. The mean of three measurements was calculated and recorded in millimeters for each reference point. As shown in Figure 5, the four values of four reference points were added together and then divided by four. The average of the four values represents the penetration ability of each sample.

## RESULTS

The mean values of penetration ability affected by finish line and elastomeric impression materials, as shown in Table 1, were normally distributed for all groups (Shapiro-Wilk's test,  $p > 0.05$ ). Levene's test for homogeneity of variance revealed statistically significant difference ( $p < 0.05$ ). The penetration ability was then evaluated with parametric tests. SPSS statistical analysis software was used for two-way analysis of variance (ANOVA) and Dunnett T3 multiple comparison tests.

The two-way analysis of variance revealed significant main effects for the type of finish line and type of elastomeric impression material, while the interaction between finish lines



**Figure 5:** A diagram of four reference points on the border of a plastic block. The distance between  $d_1$  and  $d_2$  is measured for each reference point at the border.

and impression materials was also statistically significant ( $p < 0.05$ ). Post hoc test (Dunnett's multiple comparison test) showed that PE has significantly greater penetration abilities than the other elastomeric impression materials for all types of finish lines (Figures 6 and 7). The radial shoulder group showed significantly greatest penetration ability than the other finish lines for PVS, PE, and VSE ( $p < 0.05$ ). Likewise, the radial shoulder group and heavy chamfer group had significantly the highest penetration abilities for PS ( $p < 0.05$ ). In addition, the penetration abilities of VSE and PS showed no significant differences in the radial shoulder group.

## DISCUSSION

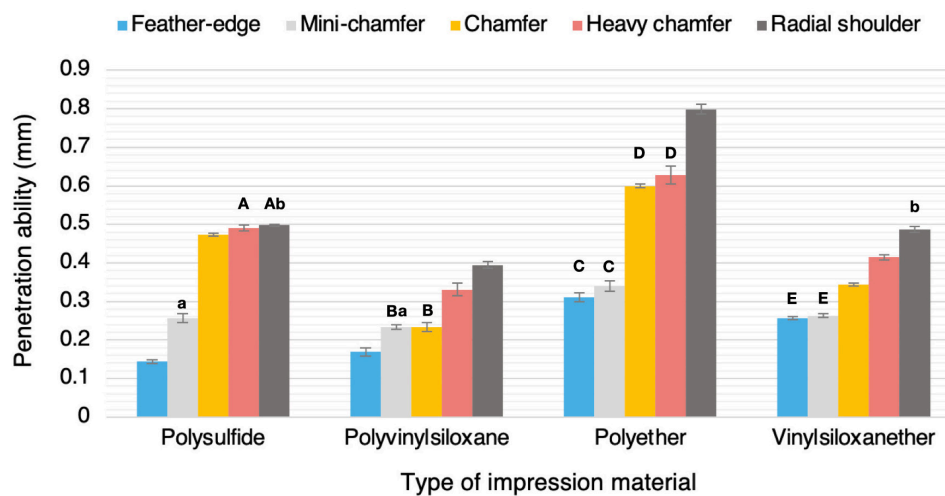
The objective of this study was to determine if different abutment finish line configurations would affect the penetrating ability of elastomeric impression materials using a simulated gingival sulcus model. According to the results of this study, both the primary and secondary null hypotheses were rejected, indicating significant differences in penetration ability among different types of elastomeric impression materials, which was also significantly influenced by the different finish line configurations.

The simulated gingival sulcus model was applied in this experiment to mimic clinically oral conditions. Previous studies showed the penetration ability of impression materials under the moisture and elasticity characteristics of the agarose gel as artificial gingival tissue, considering the presence of fluid from agar and its elasticity while seating the impression.<sup>15,17,18,22</sup> One elastic wall represents the gingiva, and the other is a solid wall representing the abutment tooth. Our simulated sulcus model was developed from a patent approved in 2020 by the Department of Intellectual Property in Bangkok, Thailand.<sup>23</sup>

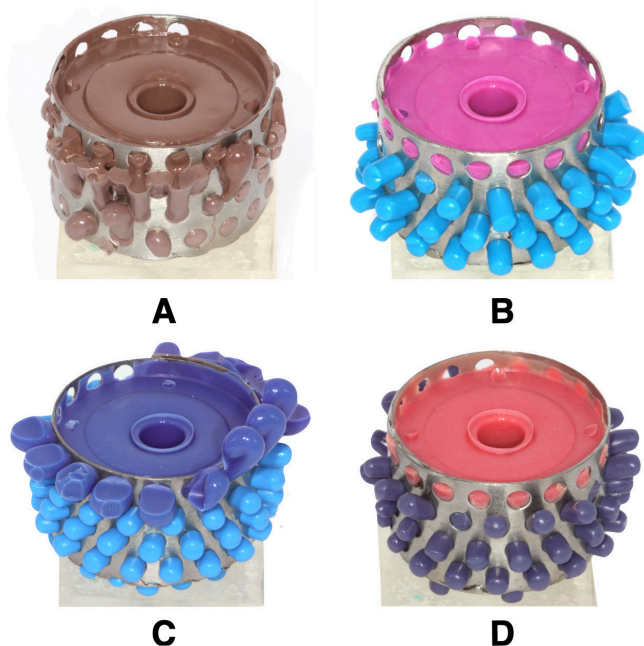
**Table 1.** Mean penetration ability in millimeters of each finish line and impression material. (standard deviations in parentheses)

Finish line type	PS	PVS	PE	VSE
Feather-edge	0.144 (0.005)	0.169 (0.011)	0.311 (0.012) <sup>C</sup>	0.257 (0.003) <sup>E</sup>
Mini-chamfer	0.257 (0.011) <sup>a</sup>	0.234 (0.006) <sup>Ba</sup>	0.340 (0.013) <sup>C</sup>	0.263 (0.005) <sup>E</sup>
Chamfer	0.474 (0.004)	0.234 (0.011) <sup>B</sup>	0.600 (0.004) <sup>D</sup>	0.344 (0.003)
Heavy chamfer	0.491 (0.007) <sup>A</sup>	0.331 (0.017)	0.628 (0.024) <sup>D</sup>	0.415 (0.007)
Radial shoulder	0.498 (0.003) <sup>Ab</sup>	0.395 (0.008)	0.799 (0.012)	0.487 (0.008) <sup>b</sup>

Note: Similar uppercase characters identified no significant differences between finish line types in the same column of impression material ( $p < 0.05$ ). Similar lowercase characters identified no significant differences between impression material types in the same row of finish line type ( $p < 0.05$ ).



**Figure 6:** Mean penetration ability of four elastomeric impression materials. Similar uppercase characters identified no significant differences between finish line types in the same of impression material. Similar lowercase characters identified no significant differences between impression material types in the same type of finish line.



**Figure 7:** Examples of each impression material using the double-mixed, double-impression technique with radial shoulder finish line model: (A) Polysulfide, (B) Polyvinylsiloxane, (C) Vinylsiloxanether and (D) Polyether

In this study, the finish line configurations and impression material affected the penetration ability of the elastomeric impression material. The study results showed that elastomeric impression materials have a greater ability to penetrate narrow gingival sulcus when the finish line is wider. The effect of finish line design was previously investigated and correlated with mechanical properties.<sup>12-14</sup> In this study, varying widths of five finish line types were designed to evaluate penetration ability. In terms of tooth preparation, 1-mm radial shoulder configurations have a greater surface area, which causes more shear stress and alters the thixotropic properties than 0.5-mm chamfer configurations.<sup>18</sup> This was consistent with the results of this research, considering that with every 0.5-mm more width of the finish line, a greater penetration ability of elastomer for all elastomeric impression materials was noted. The 0.5-mm chamfer demonstrated significantly higher penetrating ability than the feather-edge, the 0.8-mm chamfer showed significantly greater penetrating ability than the 0.3-mm mini-chamfer. The 1-mm radial shoulder also exhibited significantly higher penetrating ability than the 0.5-mm chamfer for all elastomeric impression materials in this investigation. In accordance with Jaroenpiboon

*et al.*, the penetration ability of impression material was also affected by the 1-mm radial shoulder, and the 1-mm deep chamfer presented significantly greater penetration abilities than the 0.5-mm chamfer for PE and PVS.<sup>18</sup>

From a material point of view, viscosity, thixotropic property, and hydrophilicity affect the penetration ability of elastomeric impressions.<sup>18</sup> Viscosity is defined by the ratio of dividing the shear stress by the shear rate.<sup>24</sup> Shear stress is the force per unit area that develops within fluid when an external force is applied. Shear rate is defined as the slope of the velocity-distance curve, which is the velocity of the surface divided by the distance between surfaces. Thixotropic behavior is described by the pseudoplastic (shear thinning) properties of unset elastomeric impression materials, which show that the viscosity decreases with increasing shear rate.<sup>9</sup> In other words, the greater the shear stress, the less the resistance to flow. Shaking, stirring, squeezing, patting, or vibrating gels and fluids causes them to become less viscous and flow due to steady shear forces.<sup>24</sup>

The thixotropic phenomenon of shear stress and shear rate can be found during impression-taking. When hand force is applied to the barrel of the impression syringe through the small hole of the mixed syringe tip, the viscosity decreases, enhancing flowability and allowing the material to capture and flow on crucial parts of the abutment preparation. When a fluid occupies the space between two flat surfaces, force overcomes frictional resistance within the fluid (viscosity) and causes the fluid to flow.<sup>25</sup> Shaking, stirring, squeezing, patting, or vibrating gels and other fluids cause them to become less viscous and flow due to steady shear forces.<sup>4</sup> The non-drip characteristics of unset elastomers are clinically beneficial as they restrict flow until a minimum force is applied.<sup>24</sup> As in this study design, when the upper surface of fully polymerized high-viscosity material in the impression tray was moved with a constant rate of tray seating velocity and distance, it was then seated on varying finish line types on the abutment. Greater surface area alters shear stress and decreases elastomer viscosity, due to thixotropic behavior. From the results of the present study, it can be implied that the increasing width of the finish line tends to promote the penetration ability of the elastomeric impression materials, facilitating the flowability in narrow gingival sulcus due to the thixotropic properties of the elastomers.

The penetration depth of the impression material should be more than 0.3 mm to obtain good marginal gypsum trimming and complete recording of distinguishable finish lines in impressions.<sup>7,17</sup> As a result of this study, under simulated narrow sulcus with the 0.05-mm sulcular width model, the heavy chamfer and radial shoulder finish line achieved penetration abilities of more than 0.3 mm for all types of elastomeric impression material, which is clinically acceptable. In addition, penetration ability of more than 0.3 mm was reached as well by the 0.5-mm chamfer finish line groups among the PE, PS, and VSE groups in this experiment. Furthermore, there were statistically significant differences in the penetration abilities of PE, VSE, and PVS for the chamfer group in this investigation.

In line with the experiment of Apinsathanon *et al.*<sup>15</sup> (under a similar model assembly with a narrow sulcus width and chamfer finish line model), PVS exhibited a statistically significant difference from PE. However, PE was not significantly different in penetration ability from VSE. In contrast to this study, PE and VSE showed statistically significant differences in penetration ability. The causes of these disparities could be differences in the research design.

The penetration ability of PE showed the greatest performance among other kinds of impression materials, more than 0.3 mm regardless of the type of finish line and was clinically acceptable in the present study. Similar to the findings of our investigation, earlier research also demonstrated that PE is more successful at penetrating the simulated sulcus than other kinds of impression materials.<sup>15,17,18</sup> The popular elastomeric impression materials is PE, with its hydrophilic inherent, contribute to great wetting properties and use in mild uncontrolled moisture conditions. Because of its ether-dominated polymer backbone, which allows it to penetrate wet conditions through ester functional groups and form a dipole-dipole force with water molecules, this material exhibits remarkable hydrophilicity.<sup>27</sup> The repeated activation, initiation, and propagation steps of cationic additional polymerization result in remarkable snap-set behavior of PE. In terms of the impression material, snap-set behavior implies that the material will not begin setting until the working time is ended, and when it does, it will set immediately. The development of elastic properties occurs when the materials are mixed. PVS elastomers should be utilized immediately since their elasticity quickly develops after mixing, while PE maintains its plasticity for a while before it is fully polymerized.<sup>28</sup> The long setting time of PE provides a prolonged unset period of elastomer to flow into the gingival sulcus due to its snap-set behavior. Even for feather-edge and mini-chamfer groups caused less shear stress to enhance penetration ability in present study. PE is the only material still providing penetration ability greater than 0.3 mm.

The penetration abilities of VSE and PS were comparable; both had higher penetration ability than PVS for the radial shoulder finish line group. In this study, hydrophilic PVS penetrates the gingival sulcus under moist conditions through the wettability of material related to the rearrangement of the hydrophilic part of the non-ionic surfactant on the impression surface. VSE was also developed the inherent chemistry formula, which consists of hydrophilic PE polymers and vinyl groups of PVS. Among all elastomeric impression materials, PVS had the least penetration ability in this experiment. PVS still achieved penetration depths exceeding 0.3 mm in the heavy chamfer and the radial shoulder groups. Menees *et al.* and Heuttig *et al.* stated that hydrophilic PVS and VSE show hydrophilicity properties superior to PE by contact angle analysis.<sup>16,27</sup> Nevertheless, it is considered that not only the hydrophilicity but also the viscosity are important for the penetration ability. The higher the viscosity, the greater the penetration. The PVS were less viscous than PS

and PE.<sup>29</sup> Clinically, the PE and PS materials would have a tendency to penetrate into the gingival sulcus; on the other hand, PVS have minimal resistance to displacement in subgingival areas because of their low viscosities.<sup>30</sup> This finding is consistent with Aimjirakul *et al.* who demonstrated that the penetration ability of PS was greater than that of the silicones for the narrowest sulcular width.<sup>17</sup>

For the clinical implication, our laboratory setting allowed us to simulate the clinical moist and elastic condition of the gingival sulcus in as well as assessing the properties of elastomeric impression materials. Radial shoulder finish lines or heavy chamfer can be prepared to penetrate narrow gingival sulcus in clinical condition. As a result, PE has the maximum penetration ability of all the impression material types, it is appropriate for impressions under subgingival margin and narrow gingival sulcus conditions. As alternatives, PS, VSE, and PVS all effectively penetrated the simulated narrowest sulci in our experiment. Applying these results to impression-making could be helpful from a clinical point of view. However, it should be emphasized that penetration ability is just one of the several factors that influence successful impression-taking. Considering that a greater width of the finish line provides more penetration ability for elastomeric impression material, the selection of finish line types should be based on the principle of tooth preparation and the type of restorative material.

In future studies, the simulated gingival sulcus model may be developed to apply an anatomic abutment or a chemical hemostatic agent to evaluate the penetration properties of other impression techniques in relation to various ranges of clinical usage. The surface energy of resin-based materials, oral soft tissues, and prepared teeth differs from that of stainless-steel dies, which is a limitation of this experiment. The model could potentially be improved, in order to mimic dental tissue in terms of surface energy in future investigations. Despite the fact that our model does not ideally replicate the condition in the oral cavity, it is considered appropriate for comparing the penetration abilities of impression materials under the specified moisture and elasticity factors.

## CONCLUSION

Within the limitations of this investigation, it could be stated that the finish line configuration influences the penetration ability of elastomeric impression materials in a gingival simulation model. Increased finish line width enhances the penetration ability of the elastomeric impression material. Radial shoulder and heavy chamfer finish line preparation are recommended for the clinical challenge of impression taking with subgingival margin and narrow gingival sulcus. PE has the highest penetration ability in narrow gingival sulcus compared to other elastomeric materials, regardless of abutment finish lines.

## ACKNOWLEDGMENTS

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## MANUFACTURER'S DETAILS

- Automatic dynamic mixing machine (Pentamix™3, 3M ESPE, Germany)
- Static dispenser gun (Garant™ dispenser gun, 3M ESPE, Germany)
- Computer designed software (Solidworks 2020, Dassault Systèmes Corp., USA)
- Milling machine (Feeler FTC10, FFG Group, Taiwan)
- Universal testing machine (EZ test, Shimadzu Corp., Japan)
- Agarose gel (LE agarose, Smart Science Co., Ltd, Thailand, Lot.D00199)
- Polysulfide (Heavy Bodied Permlastic®, Kerr, USA, Lot. 8639042)
- Polysulfide (Light Bodied Permlastic®, Kerr, USA, Lot. 8591232)
- Polyvinylsiloxane (Imprint™ 4 Heavy, 3M ESPE, Germany, Lot. 8718193)
- Polyvinylsiloxane (Imprint™ 4 Light, 3M ESPE, Germany, Lot. 8793599)
- Polyether (Impregum™ Penta TM Soft HB, 3M ESPE, Germany, Lot. 8368198)
- Polyether (Impregum™ Garant L Duosoft, 3M ESPE, Germany, Lot. 8713518)
- Vinylsiloxanether (Identium® Heavy, Kettenbach, USA, Lot. ND221771091)
- Vinylsiloxanether (Identium® Light, Kettenbach, USA, Lot. ND220341)
- Stereomicroscope (Olympus SZX7, Olympus Corp., Japan)
- Image analysis software (EP View, Olympus Corp., Japan)
- Statistic software (SPSS Statistics for Windows, Version 27.0, IBM Corp., USA)

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