Comparative surface detail reproduction for elastomeric impression materials: Study on reproducibility performance

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For dental impression of a prepared tooth, the goal is a void-free negative representation from which an accurate cast of a tooth and its surrounding tissue can be reproduced. This *in-vitro* study assessed and compared the reproduction accuracies of surface detail obtained with three different dental elastomeric impression materials: vinyl polysiloxane (VPS), vinyl polyether silicone (VPES), and polyether (PE). A stainless-steel model with two abutments was used, with impressions taken 10 times for each material, for 20 abutment impressions per group, using a two-phase, one-step technique (heavy body/light body). The impressions were removed and assessed for numbers of enclosed voids and open voids visible on the surface. The defect frequency was 95% for impressions with the VPS and VPES materials, and 30% for the PE material. No significant differences were seen for number of impressions with defects for VPS *versus* VPES. Significant differences were seen for VPS and VPES *versus* the PE material ($P < .05$). No significant differences were seen for the defect type distributions across these three impression materials. The PE impression material showed better accuracy for reproduction of surface detail of these dental impressions compared to the VPS and VPES impression materials.

The fabrication of well-fitting indirect prosthetic restorations is a complex process where the making of the dental impression is of particular importance. The combination of the impression material and the method is essential for the production of a successful impression, mainly in terms of dimensional accuracy and detail reproduction (1). Although there have been various technical improvements in computer-aided design and manufacturing systems and in three-dimensional imaging procedures with digital impressions (direct intraoral or indirect extraoral), the standard impression processes continue to have an important role for the transfer of information from the clinic to the dental laboratory (2, 3).

In making an impression, the goal is to provide a negative representation of the prepared tooth that is void free, thus providing an accurate cast of both the prepared tooth and its surrounding tissue (4). The ability to reproduce the surface detail in impressions of partially fixed dental prostheses in the dental laboratory has been evaluated in a number of studies. For example, Samet et al. (5) carried out a clinical study where >89% of their impressions had ≥1 visible errors. Indeed, 50.7% of their impressions

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showed tears or voids in the finish, while 40.4% showed air bubbles at the margin line, and 26.9% showed both; thus, their recommendation was that dentists are more critical in their evaluation of such impressions. Also, a report by Raigrodski et al. (6) indicated that small defects, including tears, voids, and bubbles, were present in the preparation areas of 92-96% of their control impressions, following analysis by a clinician and a dental technician.

A number of factors can have an influence on the quality and accuracy of impressions, with the most important being the mechanical properties of the elastomeric impression material (6) and the technique (7). Some studies indicated previously that the more recent improvements in the mechanical properties of elastomeric impression materials that are now available mean that the reproduction quality for surface detail is more affected by the technique used than by the impression material (4, 7-9). However, further studies have shown that the impression technique has no significant effects on the reproduction quality for surface detail of dental impressions (10-12). Thus, despite various previous studies on the quality and accuracy of impressions in terms of the importance of the materials and/or techniques used, controversy remains. These contradictory data in the literature can potentially be explained by the types of elastomeric impression materials and their related mechanical properties, along with the various protocols used to determine the quality and accuracy of impressions.

A number of impression materials are commercially available. Vinyl polysiloxane (VPS) and polyether (PE) are two impression materials that are widely used for indirect restoration in restorative dentistry, such as for inlays, onlays, veneers, fixed dental protheses, and implant-supported restorations. Previous studies have indicated the accuracy and dimensional stability of VPS and PE (13-17).

As a hydrophobic material, the correct control of moisture with VPS is of great importance for clinically acceptable impressions to be obtained, with the need to avoid the formation of voids at the margins of the tooth preparation surfaces in the impression, and thence of bubbles in gypsum casts. However, this hydrophobicity might affect the initial efficiency obtained with the impression material soon after mixing, in terms of the wet environment and its penetration into narrow spaces (14). The latest generation of VPS impression materials used clinically are known as hydrophilic or hydrophilized VPS, where there is the addition of extrinsic surfactant material. In being described as hydrophilic, this suggests that they should perform adequately when used under moist or wet conditions, by providing enhanced precision during complex clinical procedures, and thus minimizing potential clinical problems caused by voids and bubbles, and by pulls and tears (17). This enhanced hydrophilicity should improve the accuracy of impressions, as it should provide improved flow and finer detail for impressions of the moist dentinal surfaces, and also around the gingival sulcus (13). Thus, the addition of these surfactants should facilitate the making of improved impressions with better surface qualities (18), which should provide fewer defects and thus improve the stone dies (6). Furthermore, the changes to the rheological and flow characteristics of these newer hydrophilized VPS impression materials have been reported to improve their handling and adaptation to both soft and hard tissues (17).

Polyether is a hydrophilic material, composed of a relatively low molecular weight polyether, with a silica filler, and a plasticizer, which also indicates its use in moist environments. The wetting properties of PE are good, and thus gypsum casts are easier to make (18). Dimensional stability and wettability represent the most important features of such PE materials, which should result in reduced numbers of voids and more detailed reproduction of intraoral structures. On the other hand, removal of impression materials made of PE from the mouth can be difficult, and this also comes with increased risk of die breakage and might be associated with the greater rigidity of such PE materials compared to VPS (19). Of note, the newer PE impression materials have been reported to be more flexible than the previously used products, which should make it easier to remove them from the mouth (18).

A relatively new class of impression materials has also become commercially available recently: a vinyl polyether silicone (VPES; also classified as a vinyl siloxane ether or vinyl polyether siloxane) (1, 20). This was developed by combining the PE polymers and vinyl groups of VPS. It has been indicated by the manufacturer that this VPES has good mechanical properties, which includes high elastic recovery and high tear and tensile strength, along with good dimensional accuracy and flow properties. These are combined with particularly good wetting characteristics when applied to a prepared tooth under unset conditions, and also when under set conditions (1). VPES should thus combine the ease of removal of VPS and the hydrophilicity (i.e., the wetting properties) of PE, which should make it a promising material for use in complex situations where moisture control is an issue. This applies particularly to narrow, deep gingival crevices (21), where the excellent flowability through its thermosensitive rheology system allows this material to get into narrow sulcus crevices without losing its high stability (21). The accuracy of this new VPES impression material has not been established, and there are few data in the literature relating to its use (1, 18-22).

The aim of this *in-vitro* study was to examine the reproduction of surface detail of these impression materials according to their different mechanical properties, specifically through the comparison of this relatively new VPES with both the VPS and PE impression materials. The study was designed to analyze the visible defects on the surface of impressions obtained using the conventional two-phase (heavy/light body impression material), one-step impression technique. The null hypothesis here indicated that no differences would be seen for reproduction of defect-free surface detail of impressions made using these three materials despite their different mechanical properties.

MATERIALS AND METHODS

For this evaluation of the production of defect-free surface detail, impressions were made with stainless-steel abutments using stock metal trays and the three different materials with different mechanical properties. These were then examined for open voids and enclosed voids. The master model comprised a stainless-steel die with two shouldered complete-crowns, with a tapered abutment, which was constructed using a lathe, as described previously (4, 7). Each abutment had a base diameter of 12 mm, a height from the shoulder margin of 8 mm, a shoulder width of 3 mm (and thus a diameter at the shoulder margin of 6 mm), and a taper of 6 degrees; the centers of the two abutments were separated by 20 mm (Fig. 1). This standardized master model was used for comparison of the defects associated with the three impression materials used in this study. This master model was positioned manually in an autopolymerizing acrylic resin (Orthojet, Ravelli, Italy). This acrylic resin device containing the master model was then prepared for the reproducible positioning of the tray. The impressions were all made using stock metal trays (size 6; ASA Dental). For 20 experimental impressions for each of the investigated impression materials, 10 impressions of the master model (each with two abutment impressions) were made, using: VPS (Aquasil Ultra; Dentsplay International, Milford, DE); VPES (Exa'lence; GC Corporation, Tokyo, Japan); and PE (Impregum Penta Super Quick; 3M Deutschland GmbH, Neuss, Germany). All of the impressions were made using a two-phase, one-step technique with the impression materials (heavy-body and light-body) applied simultaneously, using a perforated stock metal tray for VPS and VPES, and a non-perforated stock metal tray for PE. For PE, adhesive (Polyether Adhesive; 3M Deutschland GmbH, Germany) was applied to the non-perforated stock metal tray (for 15 min), following the manufacture's instructions, for good bond strength between the PE and the metal tray. The impressions were made using the VPS, VPES and PE impression materials as detailed in Table I, with all of the impressions made by the same operator. An automatic mixing device was used to dispense the heavy-body material (Pentamix 3, 3M Deutschland GmbH, Germany), with a dispensing gun used for the light-body material (Automix; Dentsply International), along with the corresponding tips. The heavy-body mixed material was loaded into the impression tray and the light-body material was syringed around the prepared abutments and above the heavy-body material previously loaded into the impression tray. The impression tray was positioned by hand until its periphery touched the acrylic resin; it was then maintained in this position using hand pressure. As the impressions were made at room temperature (20°C) rather than mouth temperature, the polymerization times

Fig. 1. *The stainless-steel die containing 2 complete-crown, tapered abutment preparations abutments that provided the standardized master model to compare the defects associated with each of the elastomeric impression materials (base diameter of 12 mm; height from the shoulder margin of 8 mm; shoulder width of 3 mm; taper of 6 degrees; distance between the centers of the abutments of 20 mm).*

for each impression material were twice those defined by the manufacturer. The setting times used were thus 12, 14, and 8 minu for VPS, VPES and PE, respectively. After removal of the impressions, assessment of the surfaces of the abutment impressions was carried out by an examiner who had been trained in a standardized technique to recognize and classify any surface defects. For all of the surfaces of the abutment impressions, the examiner examined and counted any "bubble-like" enclosed voids (<2 mm) and any open voids (~2-4 mm) that it was possible to see with the naked eye using a working distance of ~150 mm. All of the impressions were also photographed (digital camera: Fine Pix S2pro; Fuji; AF Micro Nikkor (105 mm, 1:2.8D); Nikon). The examiner included only the defects in the impressions in and around the prepared abutments in this assessment. Clinically, precise detail registration during impression of the margin design and finish line of prepared tooth is an important factor that affects the survival of the restoration (Fig. 2). The abutment impressions were each ranked according to the number of defects: type #0, absence of defects (e.g., Fig. 3); type #1, 1 or 2 enclosed voids (e.g., Fig. 4); type #2, >2 enclosed voids (e.g., Fig. 4); and type #3, open voids seen (e.g., Fig. 5).

To evaluate the differences between the frequencies of defects across the experimental groups, the non-parametric data were analyzed using Fisher's exact tests

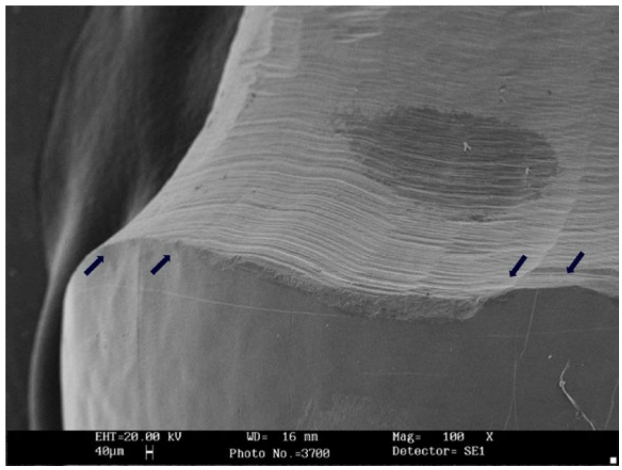

Fig. 2. *Representative image (X100) under scanning electron microscopy (Evo 50; Carl Zeiss, Oberkochen, Germany) of a prepared tooth with a chamfer margin design. It appears clear a sharp and defined finish line (arrows) on enamel. The margin was prepared by a diamond rotary cutting bur (#198 018; Komet, Lemgo, Switzerland) with an air turbine (SP 405; Faro SpA, Ornago, Italy) at 300,000 rpm.*

Table I. *Technical characteristics of the impression materials used. ISO, International Organization for Standardization (https://www.iso.org/standard/60586.html)*

Impression material	Body type	ISO 4823 type	Consistency	Lot N°	Proprietary name	Supplier
Vinyl polysiloxane	Heavy Light	2 3	Medium Light	00006234 170131	Aquasil Ultra	Dentsplay International, Milford, DE, USA
Vinyl Polyether silicone	Heavy Light	1 3	Heavy Light	1809071 1808271	Exa'lence	GC Corporation,Tokyo, Japan
Polyether	Heavy Light	1 3	Heavy Light	44058269 4405295	Impregum Penta Super Quick	3M Deutschland GmbH, Neuss, Germany

on contingency tables. The medians were obtained for each experimental group. To explore significance among the types of defects in the three impression materials, ANOVA tests were performed. The results obtained were considered significant for $P < .05$.

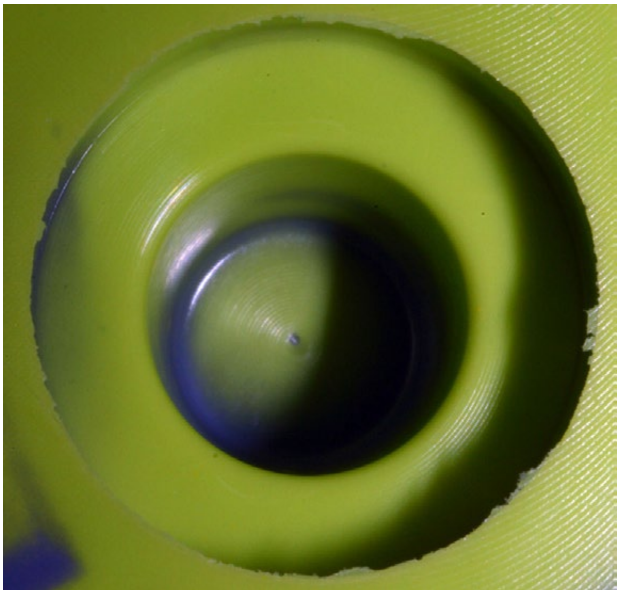

Fig. 3. *Representative impression with an absence of bubble-like enclosed voids or open voids (polyether impression material).*

RESULTS

Table II provides a summary of the identification (type) and quantification (number) of defects according to the three impression materials with different mechanical properties used here. The frequencies of the defects ranged from 95% for the VPS and VPES impression materials, to 30% for the PE impression material, with the tested groups showing a statistically significant difference ($P < .05$). For VPS *versus* VPES, there were no statistically significant differences between these defect assessments, while the differences seen for the VPS and VPES groups versus the PE group were statistically significant ($P < .05$). The data gathered here in this study thus indicated rejection of the null hypothesis. Each of the VPS and VPES impression materials produced worse results in comparison with the PE impression material. Although there were no statistically significant differences among the distributions of the defect types across each of the three impression materials, the data indicate that the PE impression material provided better results that the VPS and VPES impression materials. Here, open voids (type #3 defects) were the most frequent type

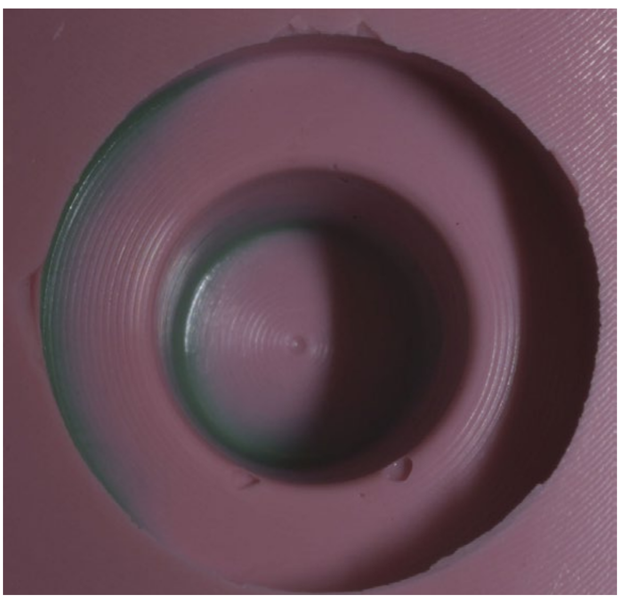

Fig. 4. *Representative impression showing some bubble-like enclosed voids (vinyl polyether silicone impression material).*

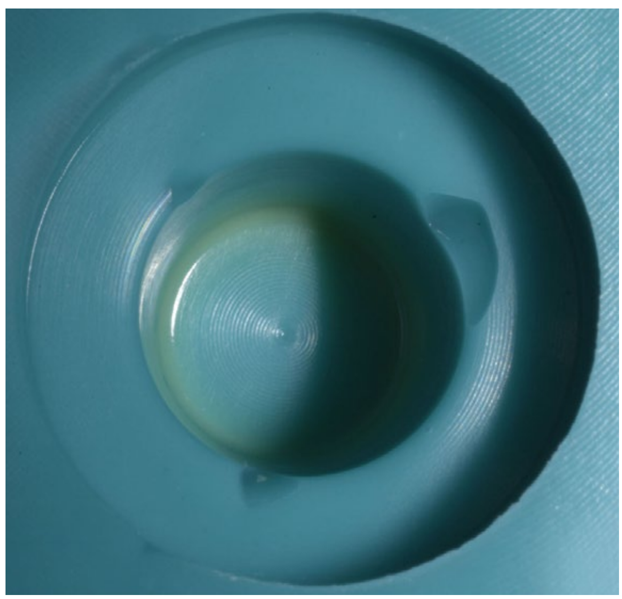

Fig. 5. *Representative impression showing some open voids (vinyl polysiloxane impression material).*

Table II. *Quantification and typing of the defects recorded for each impression material*

Impression material	Number of specimens with defects (n)	Defect frequency (%)	Defect type (n)# #1	#2	#3	Median†
Vinyl polysiloxane	19[a]	95[a]	5	2	12	3
Vinyl polyether silicone	19[a]	95[a]	5	5	9	3
Polyether	6[b]	30[b]	3	2	1	1
Significance	**[a] vs [b] <.05 (within columns)**			**>.05**		
Test	**Fisher exact test (P value)**		**ANOVA (P value)**			

#Defect type #1 (1-2 enclosed voids), type #2 (>2 enclosed voids), type #3 (presence of open voids); †Number of defect ranking.

of defect for the silicone impression materials (VPS, VPES), with enclosed voids (types #1, #2 defects) mainly seen for the PE impression material.

DISCUSSION

The present study investigated the defect frequencies of three impression materials with different mechanical properties, which showed significant differences between them. Furthermore, while the defect types for the VPS and VPES impression materials showed a fairly even distribution across enclosed voids (types #1, #2 defects) and open voids (type #3 defect), the PE impression material produced the best set of results for reproduction of detail.

To limit the number of factors that might influence the results obtained here, stock trays were applied for the three experimental groups, with the same operator making all of the impressions. Furthermore, the same technique was applied for the three impression materials examined. This appears, to the best our knowledge, to be the first *in-vitro* study to investigate the reproduction of surface detail of impression materials with different mechanical properties, in terms of VPES compared with VPS and PE, according to the types and numbers of defects that were visible on these surface impressions, including enclosed, bubble-like, voids and open voids.

Vinyl polysiloxane and PE appear to be the most accurate materials for making dental impressions on the basis of their surface reproduction and dimensional stability (23). Indeed, Lee et al. (24) did not find any significant differences in the accuracy of these impression materials. Johnson et al. (25) also showed no significant differences under dry conditions in terms of the dimensional distortion between VPS and PE when used with full-arch disposable impression trays. An *in-vitro* study has also demonstrated that the VPS and PE impression materials can penetrate and remain entrapped inside the dentinal tubules during the impression procedures, although again, this phenomenon was essentially superimposable for these two impression materials (26). In showing no significant differences between these two types of elastomeric materials, this study (26) demonstrated that both VPS and PE have high intrinsic characteristics and provide a high degree of accuracy, such that they concluded that both of these materials can reproduce the required details. Further *in-vitro* studies investigating VPS have also shown similar reproduction of detail for moist surfaces in comparison with PE (27, 28).

However, several studies have shown differences between these two impression materials (15, 29-32). VPS was reported to provide better reproduction of detail compared to PE (29, 31). On the other hand, other studies have indicated that PE is moderately hydrophilic and can provide more accurate impressions in the presence of saliva or blood, compared to VPS (18). As the wetting angle of PE is low, it can capture and reproduce the fine detail more accurately than VPS, to provide better performance (18). However, although VPS impression material has shown good enough quality in terms of detail reproduction, control of its moisture remains crucial for taking adequate impressions (6).

This study also confirms these data, whereby the PE impression material showed the lowest total number of voids among these three experimental groups, and was thus significantly better than both the VPS and VPES impression materials. In particular, the PE impression material also showed the lowest numbers of enclosed and open voids in the finish line. This will be due to the higher hydrophilicity and wettability of the PE impression material. Indeed, in the present study, PE showed defects in only 30% of the impressions. This would appear to be related to the greater liquidity of the heavy-body and light-body PE; even though these are classified as ISO viscosity types 1 and 3, respectively, a rheological study showed that at initial mixing, they are more liquid (have a higher tan δ) than the respective consistencies of VPS (32). Thus, the combination of the viscosities of the PE phases used in the present study might be better suited to avoid the creation of bubbles and open voids on the finish line. Further investigations are needed to better understand the full reasons behind this.

As indicated above, the use of VPES has been introduced more recently for conventional prosthodontics. According to the manufacturers, the chemical formulations of the VPES impression materials include a combination of both VPS and PE, purportedly to combine the best characteristics of both VPS and PE into this single, more versatile, material (1, 24, 33, 34). In an *in-vivo* study, Enkling et al. (20) showed that the performance of the VPES impression material was significantly better when compared to PE. In contrast, a further recent investigation on the accuracy of VPES, VPS, and PE as dental impression materials in implantology reported that VPS was significantly better than VPES (34). Then Baig et al. (35) concluded that the pouring of complete-arch multi-implant casts from VPES impressions provided comparable accuracy to PE.

Some studies have indeed examined the accuracy of such combinatory impression materials as compared to VPS and PE for impressions of fixed dental prostheses (1, 34); however, limited data are available at present on the accuracy of VPES used as an impression material in terms of defect-free reproduction of detail. Furthermore, to the best of our knowledge, the literature does not contain any evidence supporting the accuracy of such new hybrid materials for defect-free reproduction of detail for prosthodontic impressions. In the present study, both VPS and VPES resulted in higher numbers of voids compared to PE. Although no significant difference was seen between VPS and VPES, both of these experimental groups showed significant differences to PE. The VPS and VPES materials thus resulted in higher numbers of enclosed and open voids in the impressions, and especially in the finish line. This would appear to be due to their lower hydrophilicity and wettability, whereby in the present study the VPS and VPES impression materials resulted in defects in 95% of the impressions.

In the present study, the best outcome was, however, obtained with the PE impression material. Here, only 30% of the impressions had defects, reflecting the higher hydrophilicity and wettability of this impression material. PE is a particularly fluid material that provides good reproduction of the preparation finish line, and also of the subgingival margins. This impression material is known to have a low surface tension, which will improve the wettability of the prepared teeth. Analysis of the data in the present study indicates that this PE material can provide improved defect-free reproduction of detail compared to the other two impression materials examined here, VPS and VPES.

As well as the *in-vitro* nature of the present study, a limitation is seen in terms of the different temperature and humidity conditions to those present physiologically in the oral cavity. During standard impression making, saliva and blood might be present. Therefore, it is essential that the impression material used can sufficiently wet the surface of the dentition and gingiva when they contain moisture. In addition, the present investigation was conducted by taking impressions with only one impression technique. It would be interesting to know the behavior of these materials when tested with other impression techniques, such as the two-phase, two-step and three-phase, two-step impression injection techniques. Of note, *in-vitro* studies supported by *in-vivo* studies are needed to further explore the relative merits of the PE impression material regarding, in particular, the dimensional accuracy and how it performs in an oral environment under conditions that include saliva.

Within the above-mentioned limitations of the present *in-vitro* study, we can conclude that these different impression materials differentially affect the reproduction detail of such dental impressions. In particular, the PE impression material showed fewer defects in the reproduction of detail for these impressions compared to the VPS and VPES impression materials, based on a two-phase, one-step technique, and in terms of enclosed (bubble-like) and open voids.

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