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ORIGINAL ARTICLE

A Comparative Evaluation of Dimensional Accuracy and Surface Detail Reproduction of Four Hydrophilic Vinyl Polysiloxane Impression Materials Tested Under Dry, Moist, and Wet Conditions-An In Vitro Study

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Abstract Vinyl polysiloxane (VPS) impression materials have application in a wide variety of situations in both fixed and removable prosthodontics. A major limitation of VPS impression materials is their hydrophobicity. There are two aspects of this problem, the wettability of the polymerized impression by dental gypsum materials and the ability of the unpolymerized material to wet intraoral tissues. To address this problem, manufacturers have added surfactants and labelled these new products as "hydrophilic vinyl polysiloxane." The purpose of this study was to evaluate and compare dimensional accuracy and surface detail reproduction of four hydrophilic VPS impression materials, when used under dry, moist, and wet conditions. A total of 180 samples were made of stainless steel die similar to as described in ADA sp. no. 19. The die was scored with three horizontal and two vertical lines. Impressions were made under dry, moist and wet conditions. Dimensional accuracy was measured by comparing the length of the middle horizontal line in each impression to the same line on the metal die, by using Universal Length Measuring machine. A 2-way ANOVA was performed on the percentage change data for measured lengths of the 4 impression materials under the 3 conditions to evaluate dimensional accuracy. Surface detail was evaluated in two ways: (1) by use of criteria similar to ADA sp. no. 19 for detail reproduction, and (2) by use of a method that categorized the impressions as satisfactory or unsatisfactory based on their surface characteristics: presence of pits, voids, or roughness. Pearson X2 ($\alpha = 0.05$) was used to compare surface detail reproduction results. Conditions (dry, moist, and wet) did not cause significant adverse effects on the dimensional accuracy of all the four material. With both surface detail analyses, dry, moist, and wet conditions had a significant effect on the detail reproduction of all the four materials ($P < 0.05$). The study concluded that the dimensional accuracy of all the four impression materials tested was well within ADA standards. Best surface detail results were obtained only under dry conditions for all the four materials.

Keywords Hydrophilic VPS impression materials · Dimensional accuracy · Surface detail reproduction

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Introduction

The widespread use of addition reaction silicone impression materials, also known as vinyl polysiloxane (VPS) materials, is attributed to their dimensional accuracy and good surface detail reproducibility [1, 2]. These impression materials are widely used for obtaining dimensionally accurate models of oral tissues.

Other advantages of VPS materials include excellent elastic recovery, ease of handling, ability to produce multiple casts from one impression, and good surface detail reproducibility [1, 3, 4]. VPS impression materials set by an addition polymerization reaction and demonstrate superior dimensional stability when compared to other elastomeric impression materials, primarily because they do not release any by-products, loss of which can cause shrinkage [2–4].

Apart from these properties a limitation of VPS impression material is their inherent hydrophobic nature [2, 3] and therefore is susceptible to poor wetting of moist oral tissues and poor wetting by aqueous slurries of gypsum-based die materials. Consequently, the set gypsum casts and dies may contain pits and voids.

This hydrophobicity can be explained by the material's chemical structure, which contains hydrophobic, aliphatic hydrocarbon groups surrounding the siloxane bond [4]. In contrast, polyether and polysulphide impression materials are more hydrophilic than VPS because of chemical structures containing available functional groups that attract and interact with water molecules through hydrogen bonding. But the setting reaction of these elastomeric impression materials leaves a by-product, loss of which from the set material has a significant effect on the dimensional stability of the impression.

There are two different aspects of hydrophobic nature of vinyl polysiloxane (VPS) impression materials. The first aspect relates to the surface energy of the solid, polymerized VPS, and the high contact angle that typically forms when the VPS impressions are wetted with dental gypsum materials [5–7]. The second aspect relates to the surface energy of the unpolymerized liquid phase of the impression material, and the lack of its ability to wet oral tissues during impression making [1, 3].

To overcome this limitation of hydrophobicity, manufacturers have incorporated intrinsic surfactants (nonylphenoxy polyethanol homologues) [2, 8] and marketed these materials as hydrophilic vinyl polysiloxane impression materials. These intrinsic surfactants reduce the contact angle and improve the wettability. Hydrophilic compounds have two major aims: (1) to enhance wetting and spreading on moist oral tissues, and (2) to ensure better wettability by water containing slurries of dental gypsum materials.

These hydrophilic VPS impression materials have exhibited increased wettability of the polymerized impressions with gypsum slurries than the hydrophobic VPS [8–10]. However, when hydrophilic vinyl polysiloxane impression materials were used clinically in the presence of moisture in the form of saliva, blood, water or crevicular fluid, decreased accuracy of the impressions was reported [3]. This inaccuracy in the presence of moisture suggests that hydrophilic additives may not enhance the ability of unpolymerized VPS to wet the oral tissues under partial or complete moisture conditions, which affects the accuracy and detail reproduction of the impression. This necessitates the evaluation of these two parameters under dry, moist, and wet conditions.

Therefore, the purpose of the present study was to evaluate the dimensional accuracy and surface detail reproduction of four hydrophilic VPS impression materials, when allowed to polymerize under dry, moist, and wet conditions.

Materials and Methods

The impression materials used in this study were four hydrophilic VPS impression materials. Fifteen impressions of each material were made under each of the three conditions, dry, moist, and wet.

Material A- Affinis light body.
Material B- Panasil light body.
Material C- Affinis medium body.
Material D- Panasil medium body.

Putty impression material was not used in the study as it is a high viscosity material and the accuracy to record the surface details is less than the light body and medium body impression materials.

Die Preparation

A standardized stainless steel die (similar to that described in ADA specification no. 19), scored with three horizontal and two vertical lines, was used for sample preparation (impression making). The horizontal lines were labelled as 1, 2, and 3. The width of each horizontal line was 0.020 mm. Two cross-points at the intersection of the vertical lines with line two were marked X and X' and served as the beginning and end points of measurements for dimensional accuracy (Fig. 1). Before impression making die was ultrasonically cleaned to remove any residue and allowed to air dry. Care was taken to avoid contamination of the surface of the die before making impressions.

Sample Grouping

A total of 180 samples were prepared to compare and evaluate the dimensional accuracy and surface detail reproduction of four hydrophilic vinyl polysiloxane impression materials under dry, moist, and wet conditions (Figs. 2, 3, 4).

Impression Making

Impression material was injected onto the surface of die, using an automixing gun. Care was taken not to wear any latex gloves during material application because of their potential inhibitory effect on polymerization of VPS materials.

To make impressions under dry condition, the material was injected onto the die surface using a mixing tip (Fig. 5). The mold was then placed onto the test block to contain the material and to ensure a uniform thickness of the impression material. A cellophane sheet was placed on the impression and a rigid, flat, plastic plate was pressed over this impression to extrude the excess material. A weight of 300 g was placed on top of the plastic plate to standardize the pressure on the impression material during setting. To simulate oral conditions, this whole assembly was placed in a water bath in a glass beaker. The bath was maintained at 32 °C ± 2 °C. The mean room temperature was maintained at 22 °C. Humidity factor was not considered during impression making under dry condition.

Fig. 1 Stainless steel die with 3 *horizontal lines* (1, 2, 3) and 2 *vertical lines* (Acc. to ADA sp. no. 19). Intersection of cross lines x and x′ served as beginning and end points of line used for measurement of dimensional accuracy

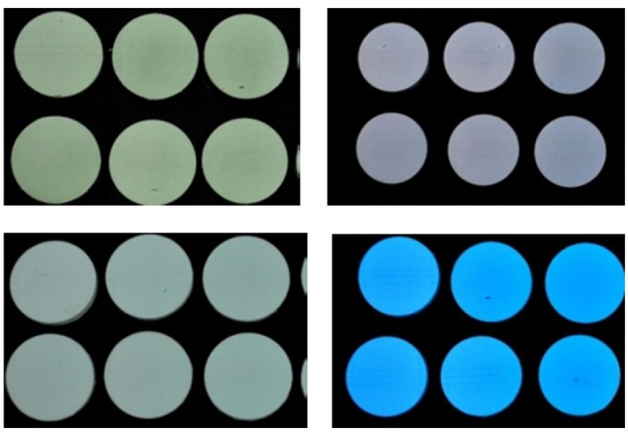


Fig. 2 Samples made under dry condition

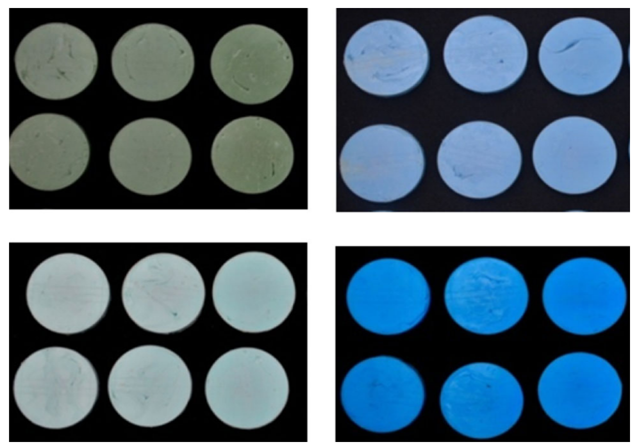


Fig. 4 Samples made under wet condition

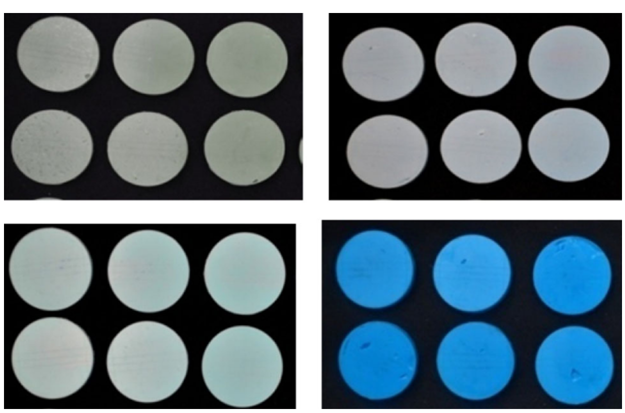


Fig. 3 Samples made under moist condition

Fig. 5 Application of impression material onto die surface (dry condition)

To make impressions under moist condition, a fine mist of water (32 °C ± 2 °C) from a spray bottle was applied to the surface of the die before the impression material was syringed onto the die surface. Care was taken to ensure that the entire die surface was covered with a uniform mist of water, avoiding any excess of water (Fig. 6). The same

Fig. 6 Preparation of sample under moist condition. **a** Mist of water on die surface before impression making. **b** Application of impression material onto die surface (moist condition)

Mist of water on die surface before impression making

Application of impression material onto die surface (moist condition)

Fig. 7 Preparation of sample under wet condition

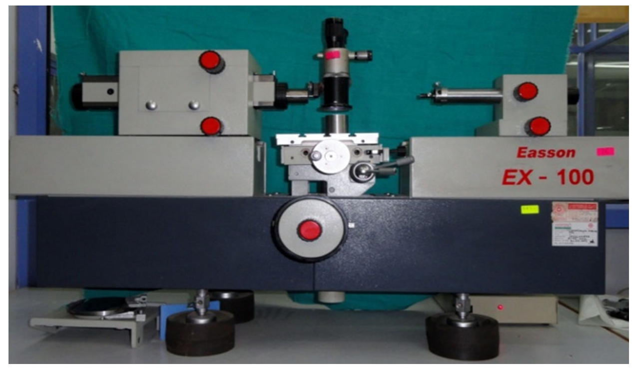


Fig. 8 Universal length measuring machine

procedure as described above was followed to obtain the impression. Vapours in environment were not considered in the study during impression making.

To make impressions under wet condition, the metal die was immersed in a water bath before the application of the impression material. With the tip of the syringe immersed under water, the material was injected onto the surface of the die, following the same procedure as described previously (Fig. 7). Impression material was directly syringed on the surface of die, immersed in the water bath, with the help of the auto-mixing gun as the set material cannot record the surface details.

The impressions were allowed to set for 3 min beyond the manufacturer's recommended time as indicated in ADA specification 19 for laboratory testing [11]. After each impression was allowed to air dry, a numeric coding system was used to ensure blind evaluation. Each impression base was marked with a number that when matched with a master sheet, corresponded to the impression material used and the condition under which the impression was made. Blinded evaluation was used for both the measurement of dimensional accuracy and the evaluation of detail reproduction. The polymerized impressions made from the four materials were of different colors; thus although the investigators could not distinguish the conditions under which the impressions were made, they could distinguish which of the four materials were used.

Humidity factor was not considered in the study only the water bath temperature (at 32 °C ± 2 °C) and mean room temperature (at 22 °C) were maintained as intra-oral environment cannot be reproduced exactly extra-orally. But the measured humidity at the time of study was 34 %.

Testing Methodology

Evaluation of Dimensional Accuracy and Surface Detail Reproduction

Dimensional accuracy was evaluated 24 h after making each impression. A single investigator measured the length of line 2 between cross points X and X' for each impression. The readings were recorded three times, using a Universal Length Measuring machine, attached with a lens. An average of these readings was taken and compared with the measurement of line 2 on the metal die used to make the impression (Figs. 8, 9).

Two independent examiners also evaluated surface detail reproduction. Surface detail reproduction was evaluated immediately after the impressions were recovered from the dies. Evaluation was achieved using two methods.

Fig. 9 Measurement of line from X to X′

The first evaluation was an assessment of the continuity of line replication according to ADA specification 19 [11] with a slight modification. Rather than only evaluating the continuity of 1 of the 3 horizontal lines in 2 out of 3 specimens, all 3 lines were assessed for each specimen. If at least 2 of the 3 horizontal lines were reproduced continuously between cross-points, the impression was considered satisfactory. All others were rated unsatisfactory.

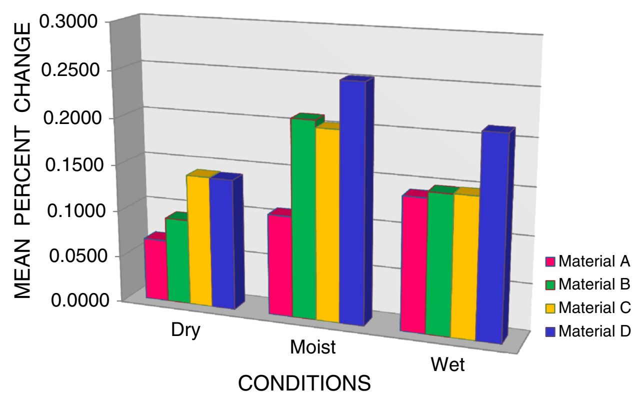
Preliminary results from the pilot study revealed that although some impressions would be rated satisfactory for detail reproduction according to the protocol described above, they could also exhibited surface characteristics such as roughness, pits, and voids on other areas of the impression. In clinical situations, if these imperfections were located in critical areas, such as preparation finish lines, they would render the impression unacceptable. It was decided that an additional evaluation of the impressions was necessary; consequently, a macroscopic evaluation of the impression's smooth surface was developed and included in this study. For this additional macroscopic evaluation, impressions were rated satisfactory if the entire impression surface was smooth, shiny, and free of voids or pits; and impressions were rated as unsatisfactory if the impression surface was rough or contained any pits or voids.

Results

Three measurements were made between cross points x and x′ (line 2) for each sample. The mean score of line 2 for each sample was calculated and compared with the line

Table 1 ANOVA between the materials in all the three conditions

Source	df	Sum of square	Mean of sum of square	F ratio	p
Between materials	3	0.21325	0.07108	10.705	<0.05
Within materials	176	1.168945	0.00664		
Total	179	1.38220			



Graph 1 Mean values of percent dimensional change between each impression material and metal die under different conditions

Table 2 ANOVA between the conditions

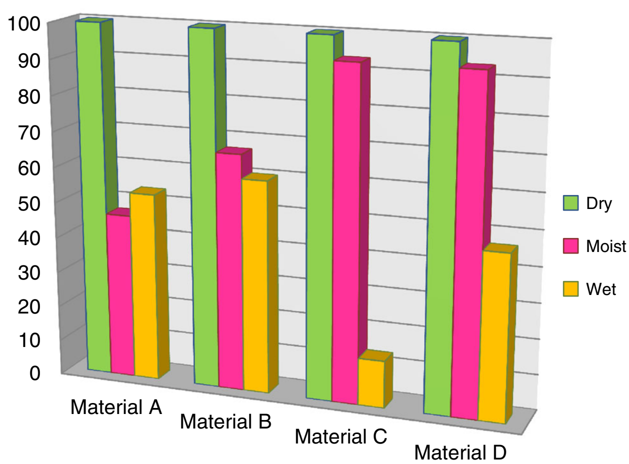
Source	df	Sum of square	Mean of sum of square	F ratio
Between material	2	0.21232	0.10616	16.0605
Within material	177	1.16988	0.00661	
Total	179	1.38220		

2 measurement obtained from the metal die used for the impression. The percent change from the metal die was computed. A 2-way ANOVA was performed on the percentage change data for measured lengths for the 4 impression materials under the three conditions to evaluate dimensional accuracy. Pearson X2 ($\alpha = 0.05$) was used to compare surface detail reproduction results.

Statistical analyses revealed that there were significant difference ($p < 0.05$) found between the four impression materials for dry, moist, and wet conditions (Table 1; Graph 1). Mean percent change across all the three conditions was found to be- for material A (0.1055 ± 0.0722), for material B (0.1502 ± 0.0774), for material C (0.1641 ± 0.0709), and for material D (0.2017 ± 0.0987). Indicating that material A exhibited less change in dimensional accuracy followed by material B, material C, and material D across all the three conditions. Whereas

Table 3 Percentage of satisfactory and unsatisfactory impressions according to criteria based on ADA specification 19 for acceptable surface detail reproduction

Impression material	Condition ($n = 15$)	Satisfactory (%)	Unsatisfactory (%)
Material A	Dry	100	0
	Moist	46.67	53.33
	Wet	53.33	46.67
Material B	Dry	100	0
	Moist	66.67	33.33
	Wet	60	40
Material C	Dry	100	0
	Moist	93.33	6.67
	Wet	13.33	86.67
Material D	Dry	100	0
	Moist	93.33	6.67
	Wet	46.67	53.33



Graph 2 Percentage of satisfactory impressions according to criteria based on ADA specification 19 for acceptable surface Detail reproduction in various conditions by each material

statistically insignificant difference was found among conditions (dry, moist, or wet) for either material (Table 2; Graph 1). Impression materials tested under dry condition exhibited less mean percent change in dimensional accuracy followed by wet and moist condition.

However, when the percent changes in dimensional accuracy were compared with ADA specification 19 standards, all the four impression materials exhibited acceptable dimensional accuracy well below 0.5 % dimensional change.

Surface detail reproduction was first evaluated based on criteria similar to ADA sp no. 19. Dry, moist, and wet conditions had significant effect on the detail reproduction for all the four impression materials. Impressions made from all the four materials under dry conditions were 100 % satisfactory. Under moist conditions only 46.67 % impressions of material A, 66.67 % impressions of material B, 93.33 % impressions of material C and 93.33 % impressions of material D were rated satisfactory. Under wet conditions only 53.33 % impressions of material A, 60.0 % impressions of material B, 13.33 % impressions of material C and 46.67 % impressions of material D were rated satisfactory (Table 3; Graph 2).

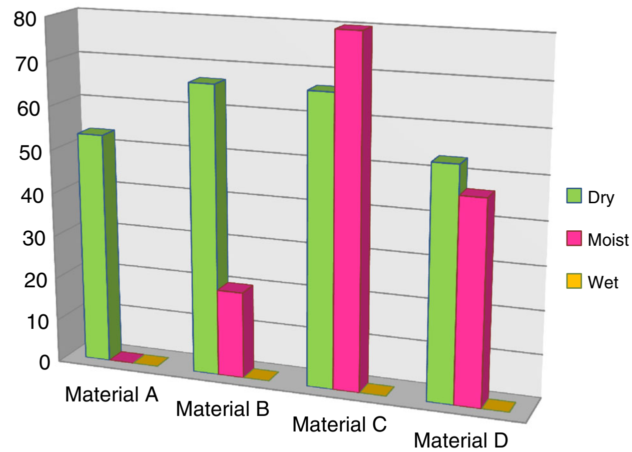
Table 4 Percentage of satisfactory and unsatisfactory impressions assessed with additional smooth surface evaluation

Impression material	Condition ($n = 15$)	Satisfactory (%)	Unsatisfactory (%)
Material A	Dry	53.33	46.67
	Moist	0	100
	Wet	0	100
Material B	Dry	66.67	33.33
	Moist	20	80
	Wet	0	100
Material C	Dry	66.67	33.33
	Moist	80	20
	Wet	0	100
Material D	Dry	53.33	46.67
	Moist	46.67	53.33
	Wet	0	100

For additional smooth surface evaluation (based on the presence of voids or pits on the impression surface) Pearson X^2 revealed that the three conditions had statistically significant effect on the detail reproduction for all the four impression materials. Under dry conditions, 53.33 % impressions of material A, 66.67 % impressions of material B, 66.67 % impressions of material C, and 53.33 % impressions of material D were smooth and shiny. Under moist conditions material A failed to produce acceptable impressions, because all impressions were pitted and voided whereas 20.0 % impressions of material B, 80.0 % impressions of material C, and 46.67 % impressions of material D were smooth and shiny. Under wet conditions all the four impression materials failed to produce acceptable impressions, because all impressions were pitted and voided (Table 4; Graph 3).

Discussion

Polyvinyl siloxane impression materials have gained their acceptance and popularity due to their excellent physical properties. Earlier studies indicated that VPS materials have demonstrated very good dimensional accuracy, ranking next to only polyether materials [3, 8, 12, 13].



Graph 3 Percentage of satisfactory impressions assessed with additional smooth surface evaluation in various conditions by each material

In spite of many advantages a major limitation of polyvinyl siloxane impression materials is their hydrophobic nature [2, 3, 8]. This hydrophobic nature of elastomeric impression materials is based on the phenomenon of contact angle formation [14]. Study done by Michalakis et al. [15] suggested that Polyether was the most hydrophilic material.

This study evaluated the dimensional accuracy of the hydrophilic VPS not only in dry, but also in moist and wet condition. The results of this study were in agreement with similar investigations done by Petrie et al. [16], Walker et al. [17] to prove that the dimensional accuracies of the hydrophilic VPS materials were not adversely affected by the presence of moisture. ADA specification 19 criteria states that elastomeric impression materials should not display more than 0.5 % dimensional change after 24 h of polymerization of the material [11]. All the four materials used in this study were well within these standards, displaying mean dimensional change of 0.1055 ± 0.0722 for affinis light body, 0.1502 ± 0.0774 for affinis medium body, 0.1641 ± 0.0709 for panasil light body, and 0.2017 ± 0.0987 for panasil medium body impression material. On comparing these materials, only under dry conditions, affinis light body performed significantly better than the other materials i.e. affinis medium body, panasil light body, and panasil medium body impression material. Same results were obtained under moist and wet conditions. There was no significant difference between conditions for each of the materials tested, implying that moisture does not affect its accuracy. Study done by Walker et al. [17], Agrawal et al. [18] also suggested that moisture did not cause significant adverse effects on the dimensional accuracy of elastomeric impression material ($p > 0.05$); however, significant differences were found between the materials ($p < 0.05$), and Affinis light body (Material A) demonstrated least dimensional change under dry, moist and wet conditions. This study also reveals that all the impression materials exhibited less dimensional changes in dry condition compared to moist and wet conditions.

In addition to the measurement of dimensional accuracy, this study also examined detailed reproduction of the hydrophilic VPS impression materials. Peutzfeldt and Asmussen [19], Takahashi and Finger [20] reported conflicting results regarding the ability of VPS impression materials to obtain complete impressions in the presence of moisture.

To evaluate the detail reproduction of the impressions made under dry, moist, and wet conditions with four impression materials, the lines (0.020-mm width) scribed on the surface of the metal die, was measured on the basis of continuous replication of at least 2 of the 3 horizontal lines on each specimen. All the four impression materials could meet this criterion 100 % of the time only under dry conditions and performed unsatisfactorily under moist and completely wet conditions. Study done by Walker et al. [17], Aiasha et al. [21] also suggested that moisture has significant effect on detail reproduction of elastomeric impression materials.

An additional macroscopic evaluation of detail reproduction of the smooth surface of the impressions was also included in the present study which was based on presence of voids, pits and roughness. The results of this additional evaluation were not consistent with the results of detail reproduction based on the continuous replication of lines. This suggests that an additional evaluation of the smoothness of the entire surface of the impression may be beneficial. The results obtained from this additional evaluation suggested that a dry field is necessary to produce clinically acceptable impressions. All the materials produced the greatest number of smooth and shiny impressions under the dry condition, but failed to produce consistently smooth and shiny impressions under the wet condition, also suggested by Aiasha et al. [21].

The fundamental focus of this study was to evaluate the ability of the VPS material to perform against wet surfaces. This study helps us to understand the limitations of hydrophilic VPS impression materials when used to record the surface detail of wet oral tissues. Although the moist surface method used in the investigation may appear more clinically relevant, the wet surface method, in which the dies were placed in water before the impression was made, was included to account for a very wet substrate, a worst case scenario. This was intended to produce a surface that was completely coated with water. This is in contrast to oral tissues where there is water at the surface, as well as water within the bulk of the tissue. Water within the bulk tissue can diffuse to the surface during the recording of an impression and it would be very difficult to duplicate such a clinical situation.

The experimental method used in this study should be considered as a preliminary testing of the accuracy and behaviour of the hydrophilic impression materials. Other investigations are necessary to assess how the material's properties are affected by the presence of saliva or moisture in the oral cavity.

The results of this in vitro investigation should be viewed cautiously because laboratory testing cannot exactly model clinical situations. In this investigation impressions were made of standardized stainless steel die. Although the metal die, calibrated for precise comparison, does not resemble the behaviour of the oral tissues. For example, metal die does not absorb liquid. In addition, the intrinsic surface-free energy of a metal die will be much higher than the surface-free energy of the proteinaceous surfaces of prepared teeth and oral soft tissues. This surface energy of the impressed surface will also affect how well the impression material will wet that surface. Another limitation of this in vitro study is that water instead of saliva was used as the source of moisture. It is well known that properties of saliva are quite different than those of water, and these differences could potentially have affected the behaviour of the impression materials.

Conclusions

Within the limitations of this in vitro study, the following conclusions can be drawn:

1. Dimensional accuracy for all the four hydrophilic VPS impression materials was not significantly affected by the dry, moist, or wet environments.
2. All the four impression materials tested satisfactorily with respect to detail reproduction under dry and moist conditions, but not under wet conditions when evaluated according to criteria similar to ADA specification No. 19.
3. Further evaluation of the impression's smooth surfaces revealed that all the four hydrophilic PVS impression materials performed satisfactorily under dry conditions but performed inconsistently under moist and wet conditions. Among all the four hydrophilic PVS impression materials, Affinis light body (Material A) and Panasil medium body (Material D) produced least number of defects.
4. Among all the four hydrophilic PVS impression materials, Affinis light body (Material A) demonstrated the most satisfactory results with least dimensional change under dry, moist, and wet conditions.
5. In all the three conditions, dry condition was found to be ideal to make the impression.

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