Basic Science Research

Pre- and Post-set Hydrophilicity of Elastomeric Impression Materials

Konstantinos X. Michalakis, DDS, PhD, FACP;[1,2] Athina Bakopoulou, DDS;[3] Hiroshi Hirayama, DDS, DMD, MS, FACP;[4] Dimitris P. Garefis, DDS, CAGS;[5,6] and Pavlos D. Garefis, DDS, PhD[7]

Purpose: To evaluate the hydrophilicity of one polyether, four poly(vinyl siloxanes), and one condensation silicone before and after setting under simulated clinical conditions, and to correlate the findings to the contact angle values of these materials.

Materials and Methods: The hydrophilicity before and after setting, as well as the contact angle values of the elastomeric impression materials were evaluated. ***Part I:*** A freshly extracted tooth, which was prepared for a full coverage restoration, was kept in saliva for 15 minutes and was then rinsed for 10 seconds. Impressions were taken without any drying of the tooth. A total of ten samples were taken for each material. The specimens were evaluated at a 10× magnification for defects. ***Part II:*** After the evaluation, the impressions were poured with a type IV dental stone and were left for 1 hour before separation. The stone specimens were then evaluated at a 10× magnification for negative voids. A total of 60 specimens were tested. ***Part III:*** Sixty identical $10 \times 10 \times 4\,\mathrm{mm}^2$ plastic molds were used for the fabrication of the impression material specimens. Contact angle measurements of each specimen were made 1 hour after separation from the plastic mold. A calibrated pipette was used to place a drop (0.05 ml) of saturated calcium sulfate dehydrate onto each specimen. Digital images were taken for each specimen, and contact angle values were measured with appropriate software.

Results: ***Part I:*** One-way ANOVA revealed significant differences among the materials ($F = 15.526$, $p < 0.0005$). Polyether had the fewest voids. The poly(vinyl siloxanes) did not present any significant differences among them, according to Tukey's HSD test ($p < 0.05$). ***Part II:*** One-way ANOVA revealed significant differences among the materials ($F = 46.164$, $p < 0.0005$). Polyether (Impregum) was the material which produced stone specimens with the fewest voids. ***Part III:*** One-way ANOVA indicated significant differences among the elastomeric impression materials ($F = 494.918$, $p < 0.0005$). Polyether displayed the smallest contact angle values.

Conclusions: Polyether was the most hydrophilic of all materials tested.

J Prosthodont 2007;16:238-248. Copyright © 2007 by The American College of Prosthodontists.

INDEX WORDS: hydrophilicity, wettability, elastomeric impression materials

[1]Adjunct Associate Professor, Division of Graduate and Postgraduate Prosthodontics, Tufts University, School of Dental Medicine, Boston, MA.

[2]Clinical Associate, Department of Fixed Prosthodontics, Aristotle University, School of Dentistry, Thessaloniki, Greece. Private Practice limited to Prosthodontics, Thessaloniki, Greece.

[3]Graduate of Postgraduate Prosthodontics and Doctoral Candidate, Aristotle University, School of Dentistry.

[4]Professor and Head, Division of Graduate and Postgraduate Prosthodontics, Tufts University, School of Dental Medicine.

[5]Doctoral Candidate, Department of Fixed Prosthodontics, Aristotle University, School of Dentistry. Private practice limited to Prosthodontics, Thessaloniki, Greece.

[6]Former Postgraduate Prosthodontics Resident, Tufts University, School of Dental Medicine.

[7]Professor and Head, Department of Fixed Prosthodontics, Aristotle University, School of Dentistry.

Accepted February 7, 2006.

This study has been conducted at the Aristotle University and conforms to the Human Subjects guidelines as presented in the World Medical Association Declaration of Helsinki, Finland in 1964 and as revised by the World Medical Assembly in Tokyo, Japan in 1975, in Venice, Italy in 1983, and in Hong Kong in 1989.

The study also conforms to the general principles of the Dental Professional Code of the European Union countries as voted in Helsinki, Finland in May, 2002.

Correspondence to: Dr. Konstantinos X. Michalakis, 3, Greg. Palama Str., Thessaloniki 546 22, Greece. E-mail: kmichalakis@the.forthnet.gr

1059-941X/07

doi: 10.1111/j.1532-849X.2007.00205.x

THE ESTABLISHMENT of a dry field is very important during final impression procedures, if an accurate impression is to be obtained.[1] This procedure is quite difficult in cases of mandibular teeth with subgingivally placed margins, since the presence of organic fluids, such as blood or saliva, can induce void formation in the impression.

Although there is a general consensus that hydrophilicity is very important for impression castability there is some controversy in the literature as to whether surface wettability is important for detailed tooth surface reproduction.[2-4]

It should also be mentioned that the rheologic characteristics, the setting rate, and general handling properties of impression materials are probably important for an accurate impression in a wet environment.[4,5] Fast kinetics of the impression materials in reaching enhanced hydrophilicity also seems to be important according to a recent study.[6]

Among the final impression materials, reversible hydrocolloid is probably the only one which has true hydrophilic properties;[7,8] however, its poor tear strength and the necessity to be poured immediately,[9,10] along with the specialized instruments needed, have limited its use.

On the other hand, an excellent impression of prepared teeth may be proven useless, if the material used has poor wetting properties, since this will lead to air entrapment and void formation in the master cast.[2] Small bubble formation on the occlusal or axial walls is usually of minor importance; however, defects on the marginal areas or at pinhole locations are very important and should be avoided.

The introduction of polyether in 1969 and of poly(vinyl siloxanes) later on, helped clinicians obtain accurate, dimensionally stable impressions. The hydrophilic properties of polyether have been recognized since its introduction.[11,12] Poly(vinyl siloxanes) though, had inherent hydrophobic properties which made both impression making and pouring with dental stone difficult. Topical surfactants increased addition silicones' wettability when poured with gypsum products, and, as a result, voids were reduced in the master casts.[13-15] Newer materials, which started being promoted in the dental market as hydrophilic in the late 1980s, are probably more easily poured with dental stone than the former poly(vinyl siloxanes).[5]

Some previous studies[16,17] concluded that the contact angles of hydrophillic poly(vinyl siloxanes) were not significantly different from those of polyether, and as a result, their castability with dental stone was comparable. These studies also suggested that there is a strong negative correlation between mean contact angles and the ability of the impression material to be poured with dental stone without air bubble entrapment. Other studies[18,19] also reported better wetting ability of the hydrophilic poly(vinyl siloxanes), when compared with that of the hydrophobic ones; however, the contact angle values of these materials were significantly higher than those of polyether.[18]

In all published research, hydrophilicity of the impression materials before setting was tested by the number of voids in the impression. In most of the studies the authors used dies,[13,15,16,19] flat dentin surfaces (with or without grooves),[4,20] or plastic teeth,[14] while the primary method of mixing was by hand spatulation after dispensing equal lengths of base and catalyst; however, mode of mixing seems to be an important factor, as it has been shown that automixing produces significantly fewer voids than hand mixing.[21] In that manner, voids that were initially attributed to the hydrophobic nature of a material could have really been caused by air entrapment during hand mixing.

The purpose of this study was to evaluate the hydrophilicity of one polyether, four poly(vinyl siloxanes), and one condensation silicone before and after setting under simulated clinical conditions, as well as to correlate the findings with the contact angle values of these materials.

Materials and Methods

One polyether, four poly(vinyl siloxanes), and a condensation silicone impression material, all medium viscosity, were compared regarding their hydrophilic properties before and after setting (Table 1). The materials included in the study were chosen because they are widely used both in the US and the European Union. All materials except President are advertised by their manufacturers as hydrophilic. The contact angle values of the impression materials were also calculated. The study consisted of three parts.

Part I: Wettability before Setting

A freshly extracted mandibular molar tooth, which was kept in 1% chloramine solution for 2 weeks,

Table 1. Elastomeric Impression Materials Tested

Brand	*Material Type*	*Batch*	*Manufacturer*
1. Impregum	Polyether	147806	3M ESPE, Seefeld, Germany
2. Aquasil	Poly (vinyl siloxane)	020812	Dentsply, Konstanz, Germany
3. Express	Poly (vinyl siloxane)	2JFB1D1	3M ESPE, St. Paul, MN
4.President	Poly (vinyl siloxane)	MI357	Coltene Whaledent, Alstatten, Switzerland
5. Reprosil	Poly (vinyl siloxane)	020910	Dentsply Caulk, Milford, DE
6. Xantopren	Condensation Silicone	90016	Heraeus Kulzer, Hanau, Germany

was embedded in autopolymerizing polymethylmethacrylate resin (ProBase, Ivoclar, Schaan, Liechtenstein).[4,20] The resin block was then placed in a pressure-polymerization apparatus (Ivomat, Ivoclar) for 15 minutes at 104°F, under a 4 bar pressure. Twenty-four hours later[20] the tooth was prepared for a full coverage restoration, with a 360° chamfer finishing line (Fig 1). A 2 mm deep and 2 mm wide ditch was made on the resin block, encircling the tooth. This ditch served a double purpose: (1) saliva and water could stagnate near the margin of the prepared tooth, and (2) it helped for the exact placement of the impression trays.

Sixty acrylic resin impression trays (SR Ivolen, Ivoclar) were fabricated at least 48 hours before impression taking.[22,23] The trays provided 3 mm thickness of impression material both occlusally and proximally. The internal walls of the trays were coated with the adhesive that each manufacturer suggested and were then left to air dry for 20 minutes.

Before taking each impression, the tooth was kept in a glass beaker containing fresh unstimulated saliva of

Figure 1. Mandibular molar prepared for a full coverage restoration and used for the purposes of this study.

Figure 2. A poly(vinyl siloxane) impression of the prepared tooth with multiple voids.

Figure 3. A polyether impression without any voids.

a healthy, non-smoking adult for 15 minutes.[17] Then it was rinsed for 10 seconds with an air–water syringe, without drying. Each impression material was automixed and then filled into an elastomer syringe (3M ESPE, Seefeld, Germany) and into the acrylic tray. The material was then syringed (via the delivering tip) around the prepared tooth, always starting from the marginal area and then moving in a circular motion towards the occlusal surface of the tooth. The delivering tip always faced the prepared tooth and was embedded in the impression material to avoid air bubble entrapment. After the injection of the impression material, the acrylic tray was placed on the tooth. All the impressions were taken by the same operator, so the repeatability of the technique could be ensured. The operator was always wearing a disposable gown, gloves, mask, and protective glasses during both the impression and pouring with gypsum procedures. This was done to protect him from biologic fluids, since the impressions were not disinfected.

The impressions were left to set at room temperature for the time suggested by the manufacturer plus an additional 15 minutes, before being separated from the tooth.[15,24]

Ten impressions were made of each material, yielding a total of 60 specimens[25,26] (Figs 2 and 3).

The impressions were evaluated under a magnification of 10×,[13] using a stereomicroscope (Olympus BH-2, Olympus Optical Co., Tokyo, Japan). The voids were recorded for each specimen.

Part II: Wettability after Setting

All impressions were poured with type IV dental stone, 1 hour after separation from the prepared tooth. The impressions were not disinfected, because the disinfection method could introduce another variable, as has been proven by many authors.[2,27,28] No topical surfactant was used.

The dental stone (GC Fujirock EP, GC Europe, Leuven, Belgium) was proportioned with water according to manufacturer's instructions (20 ml water/100 g stone), hand spatulated for 15 seconds, and vacuum-mixed (28 inches Hg) (Vacuum Power Mixer Plus, Whip Mix, Louisville, KY) for an additional 45 seconds. The stone was poured into the impressions using a No. 1 brush,[17] taking care to add small quantities of stone always from the same direction. During pouring, the impressions were held on a vibrator (Vibrator #200, Buffalo Dental Mfg Co, Syosset, NY). The medium vibrator setting was used.[16] All impressions were poured with dental stone by the same operator. The stone was allowed to set for 1 hour before separation from the impressions.

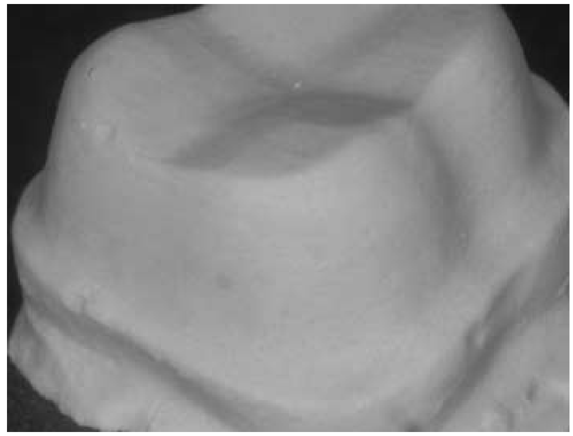


Figure 4. Stone specimen resulting from a condensation silicone impression, with multiple defects.

Each of the 60 samples (Fig 4) was inspected for defects[15] on the surface using a stereomicroscope (Olympus BH-2) at a 10× magnification.[13] The defects were recorded for each specimen.

Part III: Contact Angle Values

Sixty identical $10 \times 10 \times 4\,mm^2$ plastic molds were used for the fabrication of the impression material specimens.

Each impression material was automixed, and the plastic molds were filled directly from the automixing devices. The mixing tip was always embedded in the material to avoid any air bubble entrapment. The plastic molds were overfilled, a glass slab was placed on top of them, and hand pressure was applied for 30 seconds. In this manner the excess impression material escaped, and a flat specimen surface—free of voids—was obtained. The glass slab used was previously cleaned with ethyl alcohol and then air-dried.[16] Specimens were allowed to set for the time suggested by the manufacturer plus an additional 15 minutes, before separation from the plastic molds.[15,24]

Contact angle measurements of each specimen were taken 1 hour after separation from the plastic mold. A calibrated pipette was used to place a drop (0.05 ml) of saturated calcium sulfate dehydrate onto each specimen.[13,16]

Thirty seconds later,[24] an image of each specimen was taken using a Nikon D-100 (Nikon Corp, Tokyo, Japan) digital camera, with a Vivitar 105 mm macro lens (Vivitar, Newbury Park, CA.) and a 2× Kenko Macro Teleplus MC 7 conversion lens (Kenko Co., Tokyo, Japan) (Fig 5). The camera was fixed on a tripod. A level rule was used to align both the camera and the specimens to ensure they were horizontal.

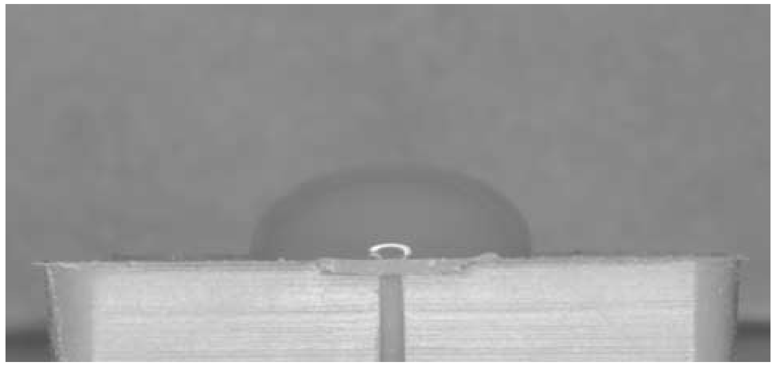


Figure 5. Drop of saturated calcium sulfate dehydrate on a poly(vinyl siloxane) sample.

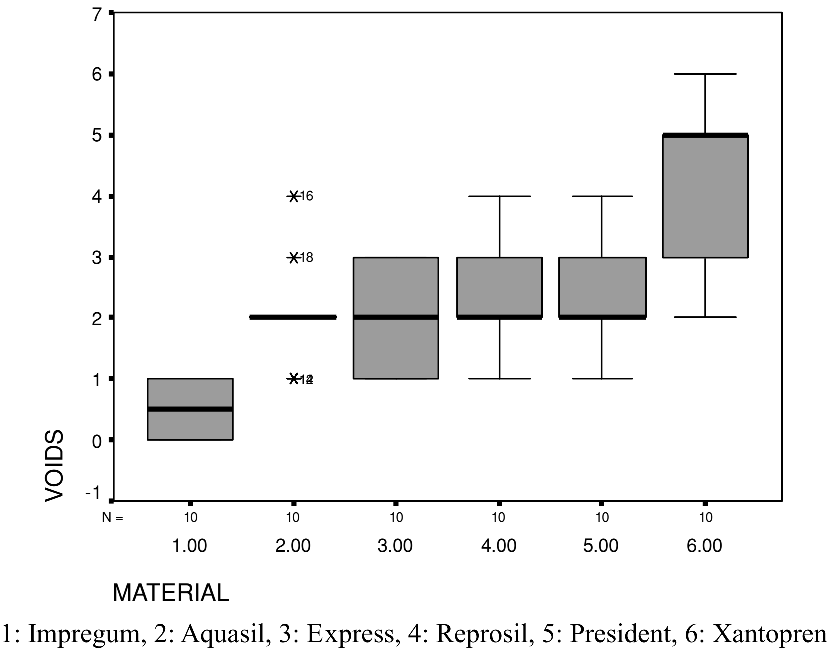


Figure 6. Box plots of the voids found in impression materials. For poly(vinyl siloxane) material Aquasil, the box plot indicates that there are seven samples with 2 voids and three samples with 1, 2, and 3 voids respectively (illustrated as*).

The contact angle values for all 60 specimens were calculated with the use of Auto CAD 2000 (Autodesk Inc, San Rafael, CA) software.

Measurements and data collection were performed independently by two operators; however, since a good correlation (Pearson correlation = 0.937) was found to exist, one set of measurements was ultimately used. Temperature and relative humidity were recorded throughout all parts of the study (21 ± 1°C, 50 ± 10%).

Table 2. Descriptive Statistics for the Voids in the Impression Materials

					95% Confidence Interval for Mean			
	N	*Mean*	*SD*	*Std. Error*	*Lower Bound*	*Upper Bound*	*Minimum*	*Maximum*
Impregum	10	0.5000[a]	.52705	.16667	.1230	.8770	.00	1.00
Aquasil	10	2.1000[b]	.87560	.27689	1.4736	2.7264	1.00	4.00
Express	10	2.1000[b]	.87560	.27689	1.4736	2.7264	1.00	3.00
Reprosil	10	2.3000[b]	.94868	.30000	1.6214	2.9786	1.00	4.00
President	10	2.3000[b]	.94868	.30000	1.6214	2.9786	1.00	4.00
Xantopren	10	4.2000[c]	1.31656	.41633	3.2582	5.1418	2.00	6.00
Total	60	2.2500	1.40971	.18199	1.8858	2.6142	.00	6.00

Means with the same superscript letter indicate no significant difference according to Tukey's HSD test ($p < 0.05$).

Table 3. Descriptive Statistics of the Voids on the Stone

	N	*Mean*	*SD*	*Std. Error*	*95% Confidence Interval for Mean* *Lower Bound*	*Upper Bound*	*Minimum*	*Maximum*
Impregum	10	0.3000[a]	.48305	.15275	−.0456	.6456	.00	1.00
Aquasil	10	1.1000[a]	.87560	.27689	.4736	1.7264	.00	2.00
Express	10	2.8000[b]	.78881	.24944	2.2357	3.3643	2.00	4.00
Reprosil	10	2.5000[b]	.70711	.22361	1.9942	3.0058	2.00	4.00
President	10	2.6000[b]	.69921	.22111	2.0998	3.1002	2.00	4.00
Xantopren	10	6.1000[c]	1.59513	.50442	4.9589	7.2411	4.00	8.00
Total	60	2.5667	2.03667	.26293	2.0405	3.0928	.00	8.00

Means with the same superscript letter indicate no significant difference according to Tukey's HSD test ($p < 0.05$).

Results

Part I

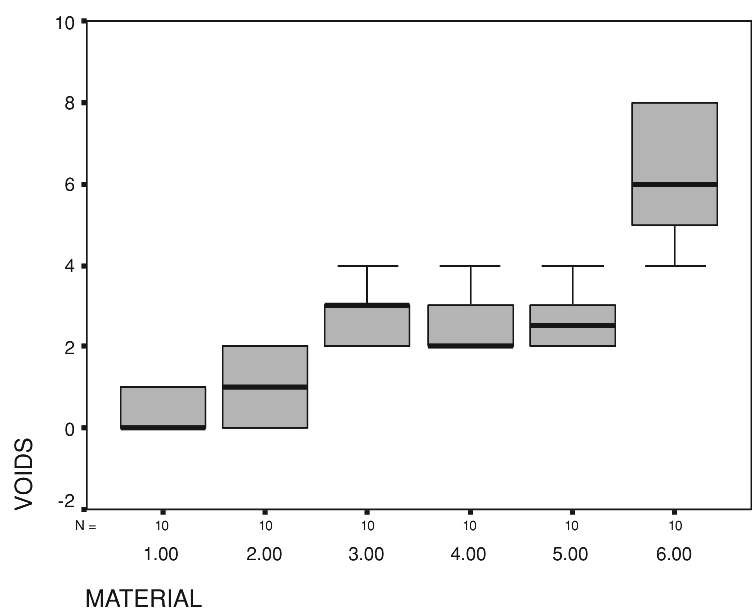
The results of the descriptive statistics for the defects in the different impression materials are depicted in Table 2 and Figure 6.

One-way ANOVA revealed significant differences ($F = 15.526, p < 0.0005$) in voids for different impression materials. None of the elastomers produced void-free impressions. Voids ranged from zero in polyether (Impregum) to six in condensation silicone (Xantopren). Poly(vinyl siloxane) material Aquasil presented seven samples with two voids. The remaining three specimens displayed one, three, and four voids. These are illustrated as extreme cases in Figure 6.

Tukey's honest significant difference (HSD) test was used to determine the significant differences among the materials. The three groups of materials [polyether, poly(vinyl siloxanes), and condensation silicone] were different ($p < 0.05$) from one another. Specifically, Aquasil and Express displayed fewer voids than Reprosil and President, but the difference was not statistically significant. Polyether (Impregum Penta) had the fewest defects, while condensation silicone (Xantopren) had the most voids.

Part II

The descriptive statistics of the voids found on the surface of the dental stone samples are illustrated in Table 3 and Figure 7.



1: Impregum, 2: Aquasil, 3: Express, 4: Reprosil, 5: President, 6: Xantopren

Figure 7. Box plots of the voids found on stone.

Table 4. Descriptive Statistics of the Contact Angle Values

Descriptives Angle	*N*	*Mean*	*SD*	*Std. Error*	*95% Confidence Interval for Mean Lower Bound*	*Upper Bound*	*Minimum*	*Maximum*
Impregum	10	35.2000[a]	2.09762	.66332	33.6995	36.7005	33.00	39.00
Aquasil	10	60.8000[b]	3.04777	.96379	58.6198	62.9802	57.00	65.00
Express	10	77.5000[c]	2.67706	.84656	75.5849	79.4151	72.00	80.00
President	10	79.7000[c]	1.76698	.55877	78.4360	80.9640	76.00	82.00
Reprosil	10	84.3000[d]	2.49666	.78951	82.5140	86.0860	81.00	88.00
Xantopren	10	73.9000[e]	3.14289	.99387	71.6517	76.1483	70.00	79.00
Total	60	68.5667	16.92192	2.18461	64.1953	72.9381	33.00	88.00

Means with the same superscript letter indicate no significant difference according to Tukey's HSD test ($p < 0.05$).

Even though extreme care was taken during gypsum pouring procedures, all impression materials presented voids in stone specimens. The number of voids ranged from zero (in samples of Impregum and Aquasil) to eight (in samples of Xantopren).

Impregum Penta (polyether) and poly(vinyl siloxane) Aquasil had fewer voids than the rest of the elastomers.

One-way ANOVA revealed that the factor "material" played an important role in the formation of voids on the stone surface ($F = 46.164, p < 0.0005$).

Tukey's HSD test revealed that the number of voids on stone specimens made of Impregum Penta and Aquasil were not significantly different ($p < 0.05$). Similarly, poly(vinyl siloxanes) Reprosil, President, and Express did not present significant differences among them. Stone samples made of Xantopren (condensation silicone) displayed the most defects.

Part III

Contact angle values were different among the six elastomers. These values ranged from 33° to 88°. The contact angle of saturated calcium sulfate dihydrate achieved on polyether was the smallest of all impression materials. The descriptive statistics are illustrated in Table 4 and Figure 8. One-way ANOVA indicated significant differences in

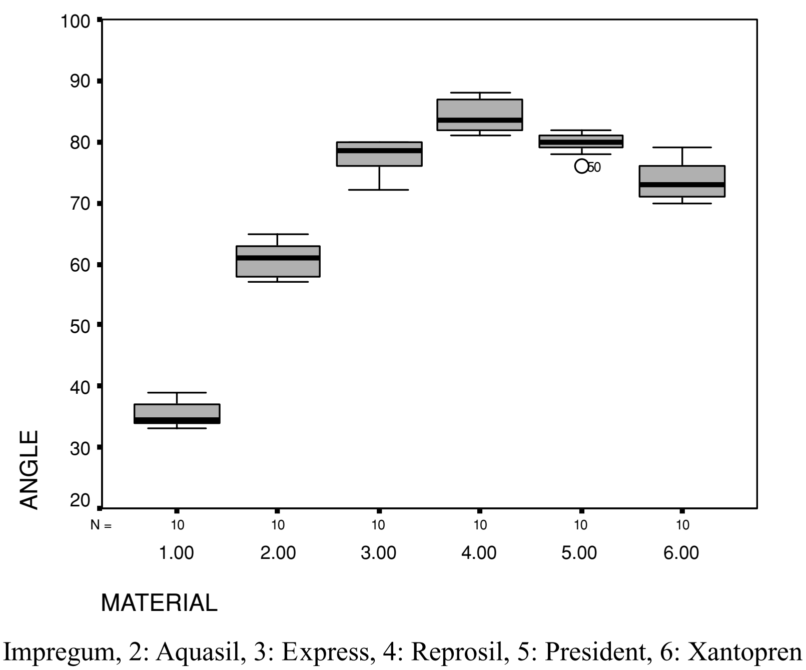


Figure 8. Box plots of contact angle values.

contact angles for different elastomeric impression materials ($F = 494.918, p < 0.0005$).

Impregum Penta (polyether) presented the lowest contact angle values, while Reprosil [poly(vinyl siloxane)] displayed the highest values.

Tukey's HSD test showed that all elastomers except the poly(vinyl siloxanes) Express and President were different from one another ($p < 0.05$). Condensation silicone Xantopren, which is advertised as hydro control, achieved lower contact angle values than poly(vinyl siloxanes) Express, President, and Reprosil; however, it did not perform as well as Impregum Penta or Aquasil.

Discussion

This study evaluated the hydrophilicity of elastomeric impression materials before and after setting under simulated clinical conditions. Additionally, it investigated any correlation between: (1) the contact angle values and the defects on the surface of the stone specimens, and (2) the defects in the impression material and the defects on the stone surface.

Two aspects of wettability should be distinguished. The first is related to the ability of the non-polymerized material to closely adapt and impress teeth surfaces and surrounding tissues. The second deals with the capacity of the set material to be poured with gypsum products without the entrapment of air bubbles, which can lead to an unacceptable stone die.[29,30]

An ideal impression material should possess hydrophilic properties both before and after setting. That means that the impression material should have a relative affinity for the liquids, which could be either water, organic fluids and/or saturated calcium sulfate dehydrate solutions. Affinity is determined by the adhesion between the molecules of the impression material and those of the liquid in contact, and actually describes their hydrophilicity. The molecules of the solid should display adhesion forces with those of the liquid. These adhesion forces should ideally exist in both the pseudoplastic and the elastic phases of the impression materials.

Hydrophilicity is considered an important property during impression procedures, as impression materials need to flow and adhere on tooth structure and periodontal tissues, which may be wetted with blood, saliva, and/or water. When these materials are hydrophilic, the water will tend to spread and ideally adhere on their surfaces. On the other hand, if a material is hydrophobic, the water will create small droplets, which will finally cause voids in the impression material. This is especially true for materials which exhibit a low viscosity, and, as a result, they cannot displace water from tooth surfaces.[4,20]

The testing method of hydrophilicity in this study was comparable to a difficult clinical situation. The conditions set were probably extreme, since in most cases an experienced clinician can achieve a relatively dry field. Even under these extreme conditions, polyether performed excellently, by registering all tooth surfaces with zero or one void per impression. This can be explained by the fact that polyether contains polar oxygen atoms, which have an affinity for water, as stated by Craig and Powers.[31] Poly(vinyl siloxanes) proved to be less hydrophilic than polyether, since they all had between one and four voids in each impression, with a mean of 2.1 or 2.3 defects. It is important to stress that there was no significant difference among the addition silicone impression materials. Reduced hydrophilicity of the examined poly(vinyl siloxanes) can be explained by the fact that these impression materials contain hydrophobic, aliphatic hydrocarbon groups surrounding the siloxane bond.[32,33] Condensation silicone Xantopren did not perform as well as the rest of the materials, with a mean of 4.2 voids per impression.

The results of this study in regards to the ability of the poly(vinyl siloxanes) to impress wet dentin agree with those of Petrie et al,[32] although in that study a metal die and water were used. In our study, a natural tooth instead of a metal die was employed, because the intrinsic surface energy of the metal is higher than the surface-free energy of the proteinaceous surfaces of dentin. This seems quite important since the surface energy of the surface to be impressed also determines how well the impression material will wet this surface.[34] Human saliva was used to approximate the conditions met in the oral environment. It is also known that saliva has different properties than those of water.[35] The latter was used only to rinse the dentin surface to simulate usual clinical techniques.

In their efforts to overcome the hydrophobic nature of the first generation of poly(vinyl siloxanes), manufacturers have added nonionic surfactants. According to Craig et al,[31] the molecules of these surfactants contain a polyether as a hydrophilic element and a part that is compatible with silicone. It is believed that there is a diffusion of these molecules into the liquid phase, altering in this way the surface tension of the liquid. The question that arises is whether these nonionic surfactants alter the intrinsic hydrophobic nature of poly(vinyl siloxanes) before or after setting. Previous articles have indicated that the term hydrophilic, when referring to addition silicones, is probably related to their ability to be poured with gypsum.[29,36,37] It has been stated that there is no scientific evidence regarding the ability of the poly(vinyl siloxanes) to flow into a wet (by water or organic fluids) sulcus and reproduce it accurately;[19,24] however, the present study indicates that there is a significant correlation between the defects in the impression material and the ones found on the surface of the stone (Pearson = 0.764, $p = 0.01$). That means that the materials that displayed fewer voids on the impression surface were also the ones that produced stone dies with fewer defects. Since these voids can be attributed only to the degree of the relative affinity of the impression material for water (as voids resulting from mixing have been ruled out) it can be assumed that the introduction of nonionic surfactants in the newer poly(vinyl siloxanes) play a role both before and after their setting. Nevertheless, this statement requires further research. It should be mentioned, however, that usually before the stone pouring procedures, impressions are treated with surfactants to improve their wettability.[29,38] This was not performed in this study, since the influence of the surfactants on the castability of the impression materials was not under investigation.

Regarding contact angle, it has been previously arbitrarily defined that materials exhibiting values greater than 90° are hydrophobic, while those exhibiting values smaller than 90° are hydrophilic.[39] A wetting angle of 0° corresponds to absolute wetting, in which the drop spreads to form a film on the surface.[40] According to this classification, all materials included in this study may be categorized as hydrophilic, since they demonstrated angles smaller than 90°. Polyether demonstrated the smallest contact angle values with a mean of 35.2°. Poly(vinyl siloxane) Aquasil had the second lowest contact angle values, with a mean of 60.8°. It is important to note that condensation silicone Xantopren demonstrated better values than Express, President, and Reprosil. This is an indication that the contact angle is not always the determining property characterizing the impressing capability and castability of a material. Other rheologic properties and ability to displace moisture seem to be important, too. Addition silicones Express and President did not present a significant difference. The present study reveals a correlation between the defects on the stone surface and contact angle values of different elastomeric impression materials (Pearson = 0.515, $p = 0.01$). It also seems that impression materials included in this study with mean values of less than 60.8° presented fewer voids on the surface of die stone specimens.

It should be mentioned, however, that this study presents two limitations. The first is that a disinfection solution was not used. This is not the case in clinical practice. Disinfection solutions should be used to prevent the spread of infectious diseases;[41-43] however, the use of a disinfection solution would introduce another parameter that would influence the contact angles (as shown by Kess et al[2] and Lepe et al[28]). The second limitation derives from the fact that newer hydrophilic poly(vinyl siloxane) impression materials were not included in the study. Since these materials seem to be promising regarding their hydrophilic properties, another study should be conducted in the near future, including those new addition silicones.

Conclusions

One polyether, four poly(vinyl siloxanes), and a condensation silicone were tested for their hydrophilic properties before and after setting under simulated clinical conditions. Their contact angle values were also evaluated. Given the limitations and methods of this laboratory study, the results were as follows:

1. Polyether (Impregum) exhibited the fewest voids before setting.
2. Stone specimens that resulted from polyether (Impregum) displayed the fewest defects; however, the results were not significantly different from those of Aquasil (poly [vinyl siloxane]).
3. Condensation silicone (Xantopren) exhibited the most voids before setting. This was also the material from which stone samples with the most defects resulted; however, its contact angle values were smaller than those of other

materials, which displayed fewer defects, such as Express, President, and Reprosil.
4. Polyether was the material that exhibited the lowest contact angle values.
5. Impression materials with mean contact angle values of less than 60.8°present fewer voids on the surface of die stone specimens.

References

1. Shillingburg HT, Hobo S, Whitsett LD, et al: Fundamentals of Fixed Prosthodontics (ed 3). Chicago, IL, Quintessence, 1997, pp. 257-279
2. Kess RS, Combe EC, Sparks BS: Effect of surface treatments on the wettability of vinyl polysiloxane impression materials. J Prosthet Dent 2000;84:98-102
3. Mondon M, Ziegler C: Changes in water contact angles during the first phase of setting of dental impression materials. Int J Prosthodont 2003;16:49-53
4. Takahashi H, Finger WJ: Dentin surface reproduction with hydrophilic and hydrophobic impression materials. Dent Mater 1991;7:197-201
5. Norling BK, Conn LJ: Wetting properties of hydrophilic and conventional poly(vinylsiloxanes). J Dent Res 1988;67(special issue):282, IADR abstract no. 1353
6. Rupp F, Axmann D, Jacobi A, et al: Hydrophilicity of elastomeric non-aqueous impression materials during setting. Dent Mater 2005;21:94-102
7. Anusavice KJ: Phillips' Science of Dental Materials (ed 10). Philadelphia, PA, Saunders, 1996, pp. 115-123
8. Nicholls, PV: Hydrophilicity? (Letter to the editor), Aust Dent J 1999;44:285-286
9. Peters MC, Tieleman A: Accuracy and dimensional stability of combined hydrocolloid impression systems. J Prosthet Dent 1992;67:873-878
10. Eriksson A, Ockert-Eriksson G, Lockowandt P: Accuracy of irreversible hydrocolloids (alginates) for fixed prosthodontics. Eur J Oral Sci 1998;106:651-660
11. Braden M, Causton B, Clarke RL: A polyether impression rubber. J Dent Res 1972;51:889-896
12. Craig RG: Status report on polyether impression materials. Council on Dental Materials and Devices. J Am Dent Assoc 1977;95:126-130
13. Norling BK, Reisbick MH: The effect of nonionic surfactants on bubble entrapment in elastomeric impression materials. J Prosthet Dent 1979;42:342-347
14. Robinson PB, Dunne SM, Millar BJ: An in vitro study of a surface wetting agent for addition reaction silicone impressions. J Prosthet Dent 1994;71:390-393
15. Cullen DR, Mikesell JW, Sandrik JL: Wettability of elastomeric impression materials and voids in gypsum casts. J Prosthet Dent 1991;66:261-265
16. Pratten DH, Craig RG: Wettability of hydrophilic addition silicone impression material. J Prosthet Dent 1989;61:197-202
17. Vassilakos N, Fernandes CP: Surface properties of elastomeric impression materials. J Dentistry 1993;21:297-301
18. Chong YH, Soh G, Setchell DJ, et al: Relationship between contact angles of die stone on elastomeric impression materials and voids in stone casts. Dent Mater 1990;6:162-166
19. Panichuttra R, Jones RM, Goodacre C, et al: Hydrophilic poly(vinyl siloxane) impression materials: dimensional accuracy, wettability, and effect on gypsum hardness. Int J Prosthodont 1991;4:240-248
20. Peutzfeldt A, Asmussen E: Impression materials: effect of hydrophilicity and viscosity on ability to displace water from dentin surfaces. Scan J Dent Res 1988;96:253-259
21. Chong YH, Soh G, Wickens JL: The effect of mixing method on void formation in elastomeric impression materials. Int J Prosthodont 1989;2:323-326
22. Pagniano RP, Scheid RC, Clowson RL, et al: Linear dimensional change of acrylic resins used in the fabrication of custom trays. J Prosthet Dent 1982;47:279-283
23. Goldfogel M, Harvey WL, Winter D: Dimensional change of acrylic resin tray materials. J Prosthet Dent 1985;54:284-286
24. Chai JY, Yeung TC: Wettability of nonaqueous elastomeric impression materials. Int J Prosthodont 1991;4:555-560
25. Knapp RG, Miller MC: Clinical Epidemiology and Biostatistics. Baltimore, MD, Williams & Wilkins, 1992, pp. 122-134
26. Glantz SA: Primer of Biostatistics. New York, McGraw Hill, 1997, pp. 78-89
27. Pratten DH, Covey DA, Sheats RD: Effect of disinfectant solutions on the wettability of elastomeric impression materials. J Prosthet Dent 1990;63:223-227
28. Lepe X, Johnson GH, Berg JC, et al: Wettability, imbibition, and mass change of disinfected low-viscosity impression materials. J Prosthet Dent 2002;88:268-276
29. Erkut S, Can G: Effects of glow-discharge and surfactant treatments on the wettability of vinyl polysiloxane impression materials. J Prosthet Dent 2005;93:356-363
30. Van Krevelen DW: Properties of Polymers: Their Correlation and Chemical Structure: Their Numerical and Prediction and Additive Group Contributions (ed 3). Amsterdam, Elsevier, 1997, pp. 7-16, 227-336
31. Craig RG, Powers JM: Restorative Dental Materials (ed 11). St. Louis, MO, Mosby, 2002, pp. 365-367
32. Petrie CS, Walker MP, O'Mahony AM, et al: Dimensional accuracy and surface detail reproduction of two hydrophilic vinyl polysiloxane impression materials tested under dry, moist, and wet conditions. J Prosthet Dent 2003;90:365-372
33. McMurry JE: Fundamentals of Organic Chemistry (ed 5). Pacific Grove, CA, Brooks/Cole Publishing, 2002, pp. 39-47, 257-268
34. Black J: Biological Performance of Materials (ed 3). New York, NY, Dekker, 1999, pp. 67-78
35. Tenuovo JO: Human Saliva: Clinical Chemistry and Microbiology, vol 1, Boca Raton, FL, CRC Press, 1989, pp. 6-25
36. Mandikos MN: Polyvinyl siloxane impression materials: an update on clinical use. Aust Dent J 1998;43:428-434
37. Lorren RA, Salter DJ, Fairhurst CW: The contact angles of die stone on impression materials. J Prosthet Dent 1976;36:176-180
38. Fernandes CP, Vassilakos N: Accuracy, detail reproduction, and hardness of gypsum casts products produced from silicone impressions treated with glow discharge. J Prosthet Dent 1993;70:457-464

39. O'Brien WJ: Dental Materials and Their Selection (ed 2). Chicago, IL, Quintessence, 1997, pp. 40-41
40. Somorjai GA: Principles of Surface Chemistry. Englewood Cliffs, NJ, Prentice Hall, 1972, pp. 72-73
41. Infection control recommendations for the dental office and the dental laboratory. Council on Dental Materials, Instruments and Equipment. Council on Dental Practice. Council on Dental Therapeutics. J Am Dent assoc 1988;116:241-248
42. Disinfection of impressions. ADA Reports (update). Council on Dental Materials, Instruments and Equipment. J Am Dent Assoc 1991;122:110
43. Infection control recommendations for the dental office and the dental laboratory. Council on Dental Materials, Instruments and Equipment; Council on Dental Therapeutics; Council on Dental Research; Council on Dental Practice. J Am Dent Assoc 1992;(123 Suppl): 1-8