Surface Quality and Long-term Dimensional Stability of Current Elastomeric Impression Materials after Disinfection

Mary P. Walker, DDS, PhD;[1] Meagan Rondeau, BS;[2] Cynthia Petrie, DDS, MS;[3] Amy Tasca, BS;[4] and Karen Williams, PhD[5]

Purpose: The objectives of this investigation were to evaluate the effect of disinfection on surface quality and dimensional stability of more recent, reformulated vinylpolysiloxane (VPS) and polyether (PE) materials.

Methods: Using ANSI/American Dental Association (ADA) specification 19 protocols, 50 impressions of stainless steel dies were made with each material. Ten impressions of each material were randomly assigned to a treatment group: (1) no disinfectant; (2) 10-minute dual phenol immersion; (3) 1-hour dual phenol; (4) 10-minute sodium hypochlorite (NaOCl); and (5) 1-hour NaOCl. Impression surface quality immediately after disinfection was categorized as smooth/shiny, matte, or wrinkled/sticky. Dimensional stability was evaluated by measuring dimensional accuracy according to specification 19 after 24-hour, 1-week, and 2-week storage at ambient laboratory conditions.

Results: The PE material surface quality was significantly affected (Pearson Chi-square, $p \leq 0.05$) by NaOCl with a mottled surface on 30% of the impressions after 10-minute immersion and a matte/sticky surface on 100% of the PE impressions after 1-hour immersion. Separate 2-factor analyses of variance (ANOVA) and Bonferroni post hoc tests of dimensional accuracy within each material indicated a significant difference ($p \leq 0.05$) between non-disinfected and disinfected PE impressions, which exhibited expansion. There were also significant differences ($p \leq 0.05$) in both VPS and PE dimensional accuracy as a function of measurement time related to increasing shrinkage over time in non-disinfected and disinfected impressions.

Conclusions: Despite PE expansion following disinfection and continued shrinkage of both the non-disinfected and disinfected VPS and PE impressions over a 2-week period, all dimensional accuracy measurements met the ADA standard, ≤0.5% dimensional change. Based on this evidence, neither NaOCl nor dual phenol disinfectants used for varying time periods adversely affected the dimensional stability of the more recent formulations of VPS and PE; however, Impregum PentaSoft PE surface quality appeared to be adversely affected by increasing exposure to NaOCl.

J Prosthodont 2007;16:343-351.

INDEX WORDS: polyether, vinylpolysiloxane, surface detail, dimensional accuracy, disinfection, hydrophilic

DISINFECTION OF impressions is recommended by the American Dental Association (ADA) and the Centers for Disease Control to prevent possible transmission of infectious diseases such as Hepatitis B, AIDS, and tuberculosis.[1,2] Disinfection protocols have changed over the years,[3-5] but current ADA guidelines state that the impression should be rinsed to remove saliva, blood, and debris, followed by immersion in a disinfecting product, such as hypochlorite, iodophor, glutaraldehyde, or phenol.[2,5] According to the Organization for Safety and Asepsis Procedures, the recommended exposure time for most surface disinfectants is 10–15 minutes;[6] however, impressions are frequently disinfected longer,

From the UMKC School of Dentistry, Kansas City, MO.

[1]Associate Professor, Director of Dental Biomaterials, Departments of Restorative Dentistry and Oral Biology.

[2]Research Assistant, Oral Biology.

[3]Assistant Professor, Restorative Dentistry.

[4]Dental student and participant in Dental Research Scholars Program.

[5]Professor, Director of Clinical Research Center, Department of Behavioral Science.

Accepted April 3, 2006.

Correspondence to: Dr. Mary P. Walker, UMKC School of Dentistry, 650 E 25th St, Kansas City, MO 64108. E-mail: walkermp@umkc.edu

1059-941X/07

doi: 10.1111/j.1532-849X.2007.00206.x

Table 1. Impression Materials Used

Product	*Manufacturer*	*Type*	*Viscosity*	*Lot Number*
Aquasil Ultra Monophase	Dentsply/Caulk, Milford, DE	Vinylpolysiloxane	Medium	050830
Impregum Penta Soft	3M ESPE, St Paul, MN	Polyether	Medium	222103

often as a result of uncontrolled timing by the dentist, i.e., disinfection between patient appointments and disinfection duplication by the dentist and laboratory.

The effect of disinfectants on impression material dimensional accuracy and surface detail reproduction has been previously investigated via direct impression evaluations and indirectly via cast measurements. Irrespective of methodology, all the investigations reported no clinically significant adverse disinfection effects on elastomeric materials such as vinylpolysiloxane (VPS) and polyether (PE);[7-20] however, there is no reported evaluation of more recently introduced, reformulated PE and "ultrahydrophilic" VPS impression materials. While PE materials are inherently hydrophilic due to their chemical structure,[21] there have been problems with impression removal due to the high stiffness of the set material.[22,23] To address this issue, some PE materials have been reformulated with less silica filler to reduce stiffness to facilitate impression removal.[24-26] In contrast to PE, VPS is inherently hydrophobic,[21,27] and to overcome this property, manufacturers have incorporated increasing amounts of surfactants[24,28] and marketed these materials as hydrophilic or ultrahydrophilic VPS. Although these formulation changes should facilitate impression making, pouring, and cast removal, it is not known whether these material modifications may affect impression material disinfectant absorption, which could potentially adversely affect the impression surface quality and dimensional accuracy. In addition, because most manufacturers report satisfactory dimensional accuracy for up to 2 weeks or even, purportedly, months,[23,29,30] there is little concern when impression pouring is delayed, or impressions are repoured after 1 to 2 weeks. Similarly, long-term dimensional stability of these reformulated impression materials could also be adversely affected by disinfectant exposure and potential absorption; however, this question has not been previously investigated.

The objectives of this investigation were to evaluate and compare the surface quality and dimensional stability of a current, reformulated PE and ultrahydrophilic VPS impression material as a function of disinfection protocol (two disinfectants with 10-minute or 1-hour exposure times).

Materials and Methods

The impression materials used in this study are presented in Table 1. Fifty impressions were made with each material. Manufacturers' mixing instructions were followed for all procedures. Based on dimensional accuracy pilot data and a power analysis, it was determined that 50 impressions (10 specimens per experimental group) would meet the constraints of $\alpha = 0.05$ and power $= 0.80$.

Standardized stainless steel dies (Fig 1) (similar to those described in ADA specification 19, ANSI/ADA 1977)[31] scored with three horizontal (0.016×20 mm) and two vertical lines were used for impression making. Impregum PentaSoft PE impressions were made using

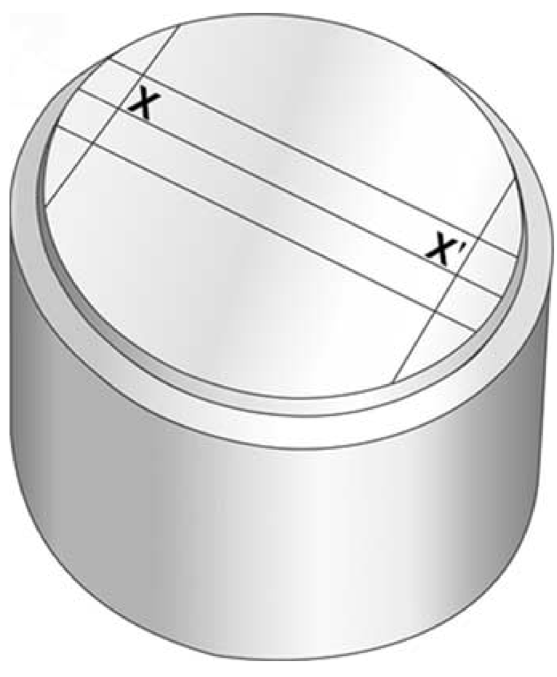

Figure 1. Stainless steel die. Intersection of cross lines at X and X′ served as beginning and end points of line used for the dimensional accuracy measurements.

prepackaged cartridges and the Pentamix electric mixing unit (3M ESPE, St. Paul, MN). Aquasil Ultra VPS impressions were made using an automixing impression gun (Dentsply/Caulk, Milford, DE) and prepackaged impression material cartridges. Latex gloves were not worn during material application because of their potential inhibitory effect on the polymerization of VPS material.[32] The cartridges were bled in compliance with manufacturers' recommendations to ensure proper dispensing ratios.

The impression material was applied to the lined area of the dies from a fine-tipped impression syringe (3M ESPE) for Impregum PE or dispensed directly from the automixing gun with an intraoral tip for Aquasil VPS. To minimize voids, the impression material was pushed ahead of the syringe tip in a zigzag pattern with the tip buried in the material. Custom-made plastic molds were placed on the beveled edges of each die to contain the material and ensure a consistent thickness of 3 mm. A polyethylene sheet (DensSilk, Reliance, Worth, IL) and a rigid, flat, metal plate were placed on top of the molds to contain the material. According to ADA specification 19, the dies with the applied impression material were transferred to a water bath maintained at $32 \pm 2°C$ to simulate polymerization in the aqueous oral environment.[31] The impressions were allowed to set for 3 minutes longer than manufacturers' recommended minimal removal time as indicated in the specification.

Ten impressions of each impression material were randomly assigned to a treatment group: (1) no disinfectant; (2) 10-minute dual-phenolic solution (dual phenol) immersion (ProPhene Plus, Certol International, LLC, Commerce City, CO); (3) 1-hour dual phenol immersion; (4) 10-minute 0.5% sodium hypochlorite (NaOCl) immersion (Clorox, Clorox Co, Oakland, CA); and (5) 1-hour NaOCl immersion. Following disinfection, the impressions were rinsed with deionized water and air-dried. All impressions were then stored at ambient room conditions.

Impression surface quality was evaluated immediately after disinfection. The surface texture was categorized as (1) smooth/shiny, (2) mottled, or (3) matte/sticky. To help explain the resultant surface quality changes seen with some of the specimens, a qualitative SEM surface characterization was also included in the investigation. Representative specimens from each experimental condition were mounted on aluminum SEM stubs, carbon coated for 30 seconds (Pelco-CC7 A SEM Carbon Coater, Clovis, CA), and observed using a Philips XL30 field-emission SEM (Philips Electron Optics, Hillsboro, OR) at 15 kV.

Dimensional stability (accuracy over time) was evaluated by measuring impression dimensional accuracy after 24-hour, 1-week, and 2-week storage. Dimensional accuracy was determined by measuring the length of the middle horizontal line (Fig 1). Two cross-points on the middle line (marked X and X′) served as the measurement beginning and end points. This measurement was made three times to the nearest 0.001 mm at 10× magnification (W126 Measuring Microscope, Gaertner Scientific, Skokie, IL). The average of the three measurements was compared with the middle line measurement of the metal die used to make the impression. The impression percent dimensional change from the metal die was computed. The percent change from the metal die was computed using the following equation:

(mean impression measurement − standard die measurement/standard die measurement) × 100.

A Pearson Chi-square ($\alpha = 0.05$) was used to compare the surface quality characterization. Separate 2-factor repeated measure ANOVAs and Bonferonni post hoc tests ($\alpha = 0.05$) were used to evaluate the effect of disinfection protocol and measurement time on dimensional stability within each material.

Results

Surface quality results are presented in Table 2. With NaOCl, there was a significant effect on the surface quality of the Impregum PE material (Pearson Chi-square, $p \leq 0.05$). After 10-minute exposure time, a mottled surface was produced on 30% of the PE impressions and after 1 hour of NaOCl exposure, a matte/sticky surface was exhibited on 100% of the PE impressions as compared with the smooth/shiny surface exhibited by 100% of the non-disinfected specimens and the specimens exposed to either 10-minute or 1-hour dual phenol. In contrast, 100% of the VPS specimens exhibited a smooth/shiny surface irrespective of the disinfection protocol. Representative surface texture examples (smooth/shiny, mottled, or matte/sticky) are presented in Figure 2. Figure 3 includes representative SEM photomicrographs of PE impressions demonstrating a smooth/shiny, mottled, or matte/sticky surface. It can be noted when comparing the SEM images, the mottled (Fig 3B) and matte/sticky surface (Fig 3C) exhibited increasing pitting as compared with the non-disinfected PE surface (Fig 3A). With the SEM characterization of VPS specimens, there was no difference in the surface between non-disinfected or disinfected impressions.

Impression material dimensional accuracy measurements (mean percent changes and standard deviations between the impression and standard die measurements) as a function of

Table 2. Surface Quality Characterization Percentages

Impression Material	*Condition N = 10*	*Smooth/Shiny (%)*	*Mottled (%)*	*Matte/Sticky (%)*
Aquasil Ultra (VPS)	No disinfectant	100	0	0
	10-minute dual phenol	100	0	0
	10-minute NaOCl	100	0	0
	1-hour dual phenol	100	0	0
	1-hour NaOCl	100	0	0
Impregum PentaSoft (PE)	No disinfectant	100	0	0
	10-minute dual phenol	100	0	0
	10-minute NaOCl	70	30*	0
	1-hour dual phenol	100	0	0
	1-hour NaOCl	0	0	100*

*Exposure to NaOCl produced a significant effect on the surface quality of Impregum PentaSoft PE (Pearson Chi-square, $p \leq 0.05$).

disinfectant protocol and measurement time are presented in Table 3. It is important to note that mean percent changes are presented as negative values, indicating the impressions were smaller than the standard die. The two-factor repeated measure ANOVA and Bonferroni post hoc test of each material indicated there was no significant difference ($p > 0.05$) in VPS dimensional accuracy as a function of disinfectant protocol, while with PE there was a significant difference ($p \leq 0.05$) between disinfected and non-disinfected impressions' dimensional accuracy. These results are related to the expansion exhibited by Impregum PE with all the disinfectant protocols (denoted by less negative values as compared with the non-disinfected PE impressions). In contrast, Aquasil Ultra VPS exhibited insignificant, minimal expansion only with 1-hour dual phenol.

The 2-factor repeated measure ANOVAs and post hoc tests also indicated there was a significant difference ($p \leq 0.05$) in dimensional accuracy among 24-hour, 1-week, and 2-week measurement times in both materials across conditions. This difference is related to both non-disinfected and disinfected PE and VPS impressions exhibiting continuing shrinkage over time as indicated in Table 3 but more easily observed in Figure 4. However, due to the initial PE expansion following disinfection, the shrinkage values of the disinfected PE impressions at 1 and 2 weeks were lower (less negative) than with either non-disinfected PE or all VPS impressions.

In spite of significant differences based on disinfection protocol or measurement time, it is important to note that all the dimensional accuracy measurements were within ADA specification 19 requirement (≤0.5% dimensional change).

Discussion

In the current investigation, impressions were made of stainless steel dies following the ADA specification for elastomeric impression materials. Although this provides a protocol that can be easily replicated by other investigators, it is not the same as making a clinical impression. For example, the protocol does not include impression trays with tray adhesive. When making an impression in a tray, impression shrinkage translates into oversized dies, which is advantageous for the fabrication of a cast restoration. The oversized die can help compensate for wax pattern and casting alloy shrinkage[33] producing a crown more likely to seat.[34] Thus, it is important that impression shrinkage is consistent, serving as a reliable factor within the expansion and shrinkage equation associated with cast restorations. This clarification is valuable in order to appreciate the clinical ramifications of dimensional accuracy changes associated with potential impression expansion following disinfection.

With the introduction of reformulated impression materials, it is important to evaluate whether the material modifications might affect dimensional accuracy or surface quality with disinfection. In this investigation with either NaOCl or dual phenol disinfectant used for 10 minutes or 1 hour, Aquasil Ultra VPS or Impregum PentaSoft PE dimensional accuracy measured over a 2-week period was not adversely affected. According to ADA specification 19 criteria, elastomeric impression material should not exhibit more than 0.5% dimensional change within the first 24 hours.[31] At the 24-hour dimensional accuracy measurement, all the disinfected and non-disinfected

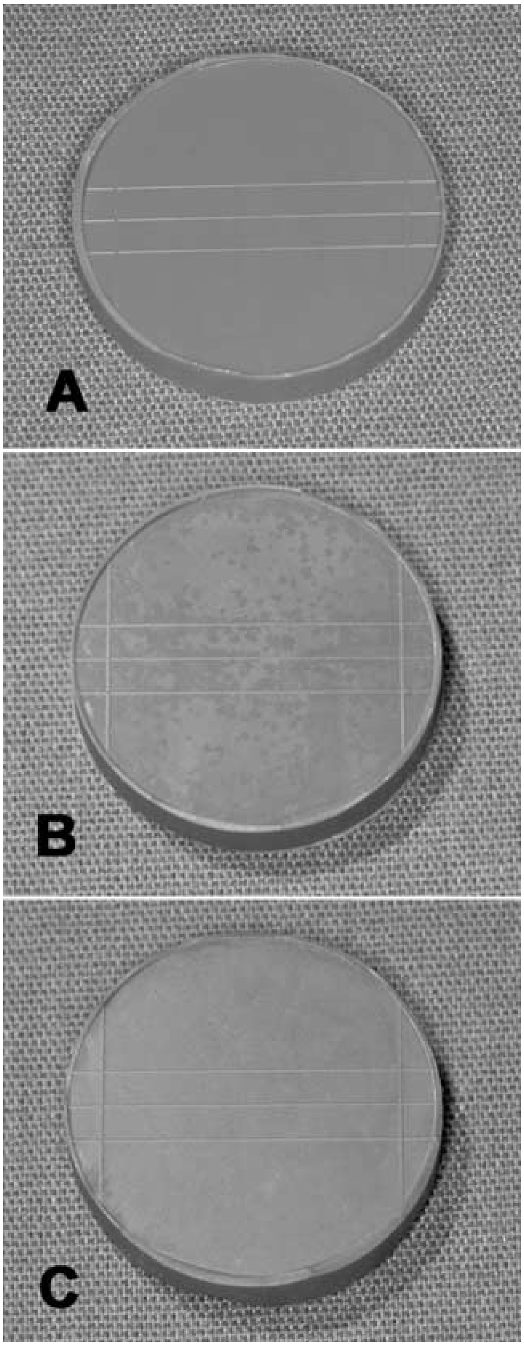

Figure 2. Representative surface quality examples. (*A*) smooth/shiny; (*B*) mottled; and (*C*) matte/sticky.

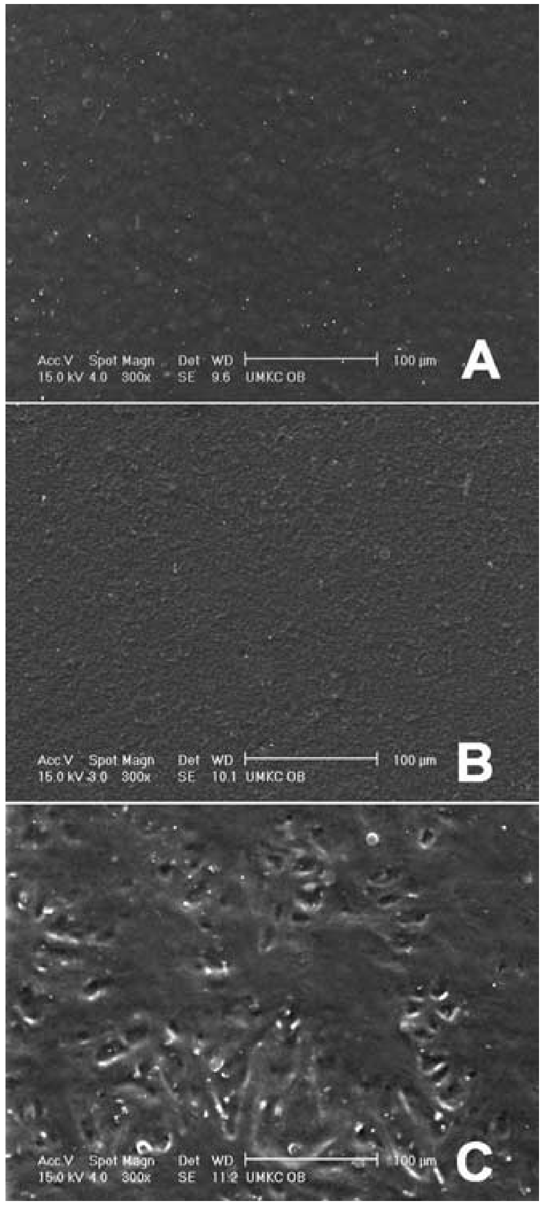

Figure 3. Representative SEM images of Impregum PE surfaces: (*A*) smooth/shiny (no disinfection); (*B*) mottled (10-minute NaOCl); and (*C*) matte/sticky (1-hour NaOCl).

impressions made with the more recent impression materials were within this standard. Although there have been numerous disinfection investigations of previous formulations of VPS and PE materials, it is difficult to directly compare the results of this study with those investigations, due to varying experimental protocols. Rather than following the ADA specification protocol, the previous investigations assessed impression accuracy using a variety of procedures, such as measuring impression shrinkage with a non-contact displacement meter[9] or indirectly evaluating impression accuracy by measuring resultant casts with various configurations.[7,11,13,18,19,35] However, in spite of methodology differences, all the previous studies

Table 3. Dimensional Accuracy Measurements: Means (SD) of Percent Dimensional Change Between Impressions and Metal Dies at Three Measurement Times

Impression Material	*Condition N = 10*	*24-hour*	*1-week***	*2-week***
Aquasil Ultra (VPS)	No disinfectant	−0.32 (0.05)	−0.40 (0.06)	−0.42 (0.09)
	10-minute dual phenol	−0.28 (0.09)	−0.39 (0.07)	−0.40 (0.06)
	10-minute NaOCl	−0.30 (0.04)	−0.37 (0.09)	−0.40 (0.09)
	1-hour dual phenol	−0.19 (0.10)	−0.29 (0.11)	−0.34 (0.10)
	1-hour NaOCl	−0.31 (0.04)	−0.36 (0.05)	−0.40 (0.07)
Impregum PentaSoft (PE)	No disinfectant	−0.27 (0.09)	−0.34 (0.10)	−0.42 (0.09)
	10-minute dual phenol	−0.17 (0.06)*	−0.24 (0.09)	−0.30 (0.10)
	10-minute NaOCl	−0.16 (0.02)*	−0.23 (0.05)	−0.28 (0.02)
	1-hour dual phenol	−0.13 (0.09)*	−0.26 (0.08)	−0.27 (0.09)
	1-hour NaOCl	−0.11 (0.07)*	−0.24 (0.09)	−0.27 (0.10)

*There was significant PE expansion following all disinfection protocols ($p \leq 0.05$), while there was no significant change in VPS dimensional accuracy following disinfection.
**Both non-disinfected and disinfected VPS and PE impressions exhibited significant increasing shrinkage over time ($p \leq 0.05$).

reported no adverse disinfection effects on the short-term dimensional accuracy of previous formulations of VPS and PE materials.[7,9,11,13,18,19,35] Those results agree with the 24-hour dimensional accuracy results of the newer formulation materials in this study. Furthermore, even over a 2-week measurement period, all the disinfected and non-disinfected impressions in the current study were within the dimensional accuracy standard. Long-term dimensional stability as a function of disinfection protocols has not been previously reported.

Although all dimensional changes throughout this investigation were within the specification standard, Impregum PentaSoft PE exhibited statistically significant ($p \leq 0.05$) expansion with all disinfectant protocols as compared with the non-disinfected PE impressions. In contrast, disinfected Aquasil Ultra VPS did not exhibit significant ($p > 0.05$) expansion as compared with the non-disinfected VPS impressions. These differences in PE vs. VPS expansion as related to potential disinfectant absorption are in agreement with previous PE and VPS studies, which reported greater disinfectant absorption with Impregum Garant as compared with Aquasil.[10,11]

Thus, in spite of the reformulation to produce an ultrahydrophilic, "smart wetting" material marketed as Aquasil Ultra VPS, the material still appears to behave as a more hydrophobic material with less expansion than PE. In contrast to VPS, PE is inherently hydrophilic; and with reduced silica filler content to reduce stiffness, there was the potential for increased moisture absorption as reported with other polymers when filler content is reduced.[36,37] However, even with reduced silica filler, PE disinfection did not produce expansion beyond the ADA specification criteria. Nevertheless, it is important to note that PE disinfectant expansion appears to be time dependent, with 1-hour immersion in NaOCl or dual phenol producing more expansion than 10-minute immersion in both solutions.

As already indicated, all dimensional accuracy measurements in the investigation were within the specification standard even at the 2-week measurement. This information is especially valuable in situations when impressions must be repoured later; however, there was a significant effect of measurement time on the dimensional accuracy of both materials, related to the continuing shrinkage that occurred over the 2-week measurement period with maximum shrinkage of 0.42%. These results suggest that with continued storage, dimensional accuracy values might go beyond the ADA standard (0.5% dimensional change). Thus, even though some manufacturers have suggested that impressions can be repoured for weeks or months,[29,30] repouring beyond 2 weeks might not be acceptable.

In addition to impression material dimensional accuracy, this study also evaluated the effect of the disinfectant protocols on impression surface quality categorized as smooth/shiny, mottled, or matte/sticky (Fig 2). The VPS surface quality was not adversely affected by either NaOCl or dual phenol after 10-minute or 1-hour immersion. In contrast, the PE material surface quality was significantly affected by NaOCl immersion with

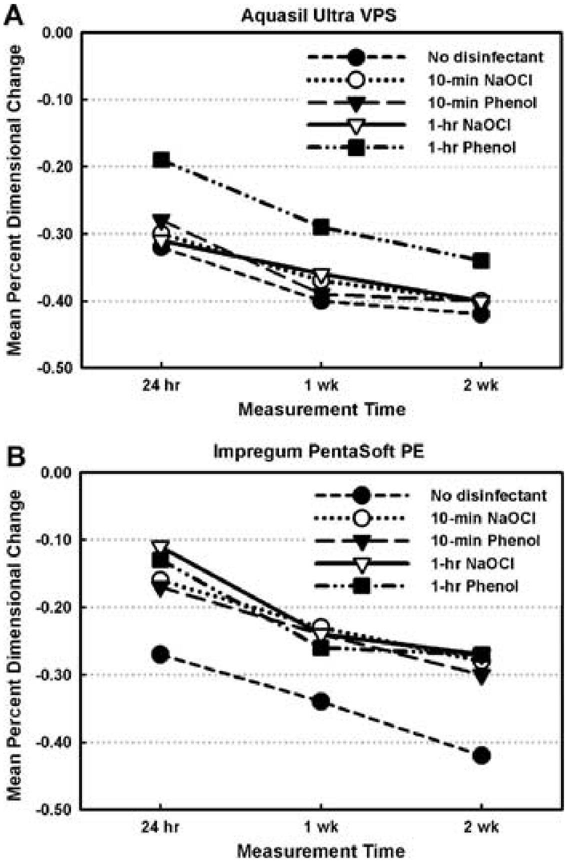

Figure 4. Dimensional accuracy as a function of disinfectant protocol and measurement time for Aquasil Ultra VPS (*A*) and Impregum PentaSoft PE (*B*) impression materials (N = 10 impressions per disinfection protocol). There was significant ($p \leq 0.05$) PE expansion following disinfection. In spite of minimal VPS expansion with 1-hour dual phenol, there was no significant difference ($p < 0.05$) between disinfected and non-disinfected VPS impressions. Both non-disinfected and disinfected VPS and PE impressions exhibited significant shrinkage over time ($p \leq 0.05$).

a mottled surface on 30% of the impressions after 10-minute immersion and a matte/sticky surface on 100% of the PE impressions after 1-hour immersion. With the PE specimens exhibiting a matte/sticky surface, although the die lines were replicated, the overall sharpness of the impression surface detail was reduced. In addition, these impressions were even difficult to handle due to the sticky surface. Such changes in the impression material could be expected to produce less than optimal cast surfaces. With the additional SEM characterization to help explain the PE surface quality changes with NaOCl, it was noted that the impression surface appeared pitted, with increasing changes from the mottled to matte/sticky specimens (Fig 3). While this surface change could potentially be explained by disinfectant absorption, similar surface changes were not seen macroscopically or microscopically with PE dual phenol immersion in spite of the expansion with dual phenol. This would suggest that in addition to NaOCl absorption by PE, there might be an adverse interaction between NaOCl and PE resulting in impression surface degradation.

Other investigations evaluating surface quality and detail reproduction following impression material disinfection have not reported adverse surface changes with immersion disinfection;[7,8,19,20] however, those studies did not include NaOCl as one of the disinfectant solutions. Previous dimensional accuracy investigations using NaOCl immersion disinfection, although not directly evaluating surface quality, have not noted any adverse change in the PE surface; however, those investigations were using Impregum F, a much earlier PE formulation.[9,12,13,17]

As with any in vitro investigation, there are limitations. When making evaluations according to an ADA specification, the protocol will not exactly simulate the clinical application; however, following a specification protocol for in vitro investigations is valuable to facilitate study replication and direct comparisons between studies, which to date is limited due to investigation protocol variability. Even though the specification does not include pouring casts from impressions made in trays with adhesive, the effect of impression shrinkage and expansion can still be related to the clinical situation. As already explained, impression shrinkage in a tray produces oversized dies, a positive factor associated with cast restorations.[34] In the current investigation, while both disinfected and non-disinfected VPS exhibited similar shrinkage, even the disinfected, expanded PE impressions still exhibited overall shrinkage, albeit less than the non-disinfected PE impressions.

Conclusions

1. Impregum PentaSoft PE significantly expanded following disinfection with NaOCl or dual phenol, while there was no significant change in Aquasil VPS dimensional accuracy following disinfection. Both non-disinfected and disinfected VPS and PE impressions

exhibited increasing shrinkage over the 2-week measurement period; however, all measurements met the ADA standard (≤0.5% dimensional change).

2. There was a significant adverse effect on the surface quality of Impregum PentaSoft PE with increasing exposure to NaOCl.
3. Although disinfection does not appear to adversely affect dimensional accuracy/stability of the more recent VPS and PE materials, the results of this investigation suggest that not all disinfectant solutions produce optimal impression surface quality with the newly formulated PE.

Acknowledgments

The authors appreciate materials provided by 3M ESPE and Dentsply/Caulk.

References

1. Centers for Disease Control and Prevention: Recommended infection-control practices for dentistry. MMWR Morb Mortal Wkly Rpt 1993;42(RR-8):1-12
2. ADA Council on Scientific Affairs and ADA Council on Dental Practice: Infection control recommendations for the dental office and the dental laboratory. J Am Dent Assoc 1996;127:672-680
3. Council on Dental Materials, Instruments, and Equipment, Council on Dental Practice, and Council on Dental Therapeutics: Infection control recommendations for the dental office and the dental laboratory. J Am Dent Assoc 1988;116:241-248
4. Council on Dental Materials, Instruments, and Equipment, and Council on Dental Therapeutics: Infection control recommendations for the dental office and the dental laboratory. J Am Dent Assoc 1992 Aug;(Suppl):1-8
5. Cottone JA, Young JM, Dinyarian P: Disinfection/sterilization protocols recommended by manufacturers of impression materials. Int J Prosthodont 1990;3:379-383
6. Organization for Safety and Asepsis Procedures: Chemical Agents for Surface Disinfection. Annapolis, MD, OSAP, 1998
7. Lepe X, Johnson GH, Berg JC: Surface characteristics of polyether and addition silicone impression materials after long-term disinfection. J Prosthet Dent 1995;74:181-186
8. Bergman M, Olsson S, Bergman B: Elastomeric impression materials. Dimensional stability and surface detail sharpness following treatment with disinfection solutions. Swed Dent J 1980;4:161-167
9. Oda Y, Matsumoto T, Sumii T: Evaluation of dimensional stability of elastomeric impression materials during disinfection. Bull Tokyo Dent Coll 1995;36:1-7
10. 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
11. Lepe X, Johnson GH: Accuracy of polyether and addition silicone after long-term immersion disinfection. J Prosthet Dent 1997;78:245-249
12. Langenwalter EM, Aquilino SA, Turner KA: The dimensional stability of elastomeric impression materials following disinfection. J Prosthet Dent 1990;63:270-276
13. Adabo GL, Zanarotti E, Fonseca RG, et al: Effect of disinfectant agents on dimensional stability of elastomeric impression materials. J Prosthet Dent 1999;81:621-624
14. al-Omari WM, Jones JC, Wood DJ: The effect of disinfecting alginate and addition cured silicone rubber impression materials on the physical properties of impressions and resultant casts. Eur J Prosthodont Restor Dent 1998;6:103-110
15. Davis BA, Powers JM: Effect of immersion disinfection on properties of impression materials. J Prosthodont 1994;3:31-34
16. Giblin J, Podesta R, White J: Dimensional stability of impression materials immersed in an iodophor disinfectant. Int J Prosthodont 1990;3:72-77
17. Herrera SP, Merchant VA: Dimensional stability of dental impressions after immersion disinfection. J Am Dent Assoc 1986;113:419-422
18. Jagger DC, Al Jabra O, Harrison A, et al: The effect of a range of disinfectants on the dimensional accuracy of some impression materials. Eur J Prosthodont Restor Dent 2004;12:154-160
19. Johnson GH, Chellis KD, Gordon GE, et al: Dimensional stability and detail reproduction of irreversible hydrocolloid and elastomeric impressions disinfected by immersion. J Prosthet Dent 1998;79:446-453
20. Johnson GH, Drennon DG, Powell GL: Accuracy of elastomeric impressions disinfected by immersion. J Am Dent Assoc 1988;116:525-530
21. Walker MP, Petrie CS, Haj-Ali R, et al: Moisture effect on polyether and polyvinylsiloxane dimensional accuracy and detail reproduction. J Prosthodont 2005;14:158-163
22. Chai JY, Yeung TC: Wettability of nonaqueous elastomeric impression materials. Int J Prosthodont 1991;4:555-560
23. O'Brien WJ: Dental Materials and Their Selection (ed 3). Chicago, IL, Quintessence, 2002, pp. 90-112
24. Craig RG, Powers JM: Restorative Dental Materials (ed 11). St Louis, Mosby-Year Book, Inc, 2002, pp. 348-367
25. Lu H, Nguyen B, Powers JM: Mechanical properties of 3 hydrophilic addition silicone and polyether elastomeric impression materials. J Prosthet Dent 2004;92:151-154
26. 3M ESPE: Impregum Penta Soft: Technical product profile. St Paul, MN, 2001
27. Anusavice KJ: Phillips' Science of Dental Materials (ed 11). Philadelphia, PA, Saunders, 2003, pp. 205-231
28. Craig RG, O'Brien WJ, Powers JM: Dental Materials. Properties and Manipulation (ed 6). St. Louis, MO, Mosby, 1996, pp. 136-177
29. Coltene Whaledent Inc: Impression materials [cited 2005 Dec 20]. Available at http://www.coltenewhaledent.com
30. GC America, Inc: Impression materials [cited 2005 Dec 20]. Available at http://www.gcamerica.com
31. ANSI/ADA: American National Standards Institute/American Dental Association: Specification No. 19 for non-aqueous, elastomeric dental impressions. J Am Dent Assoc 1977;94:733-741;addendum 1982;1105:1686

32. Kahn RL, Donovan TE, Chee WW: Interaction of gloves and rubber dam with a poly(vinyl siloxane) impression material: a screening test. Int J Prosthodont 1989;2:342-346
33. Anusavice KJ: Phillips' Science of Dental Materials (ed 11). Philadelphia, PA, Saunders, 2003, pp. 289, 577
34. Bailey JH, Donovan TE, Preston JD: The dimensional accuracy of improved dental stone, silverplated, and epoxy resin die materials. J Prosthet Dent 1988;59:307-310
35. Wadhwani CP, Johnson GH, Lepe X, et al: Accuracy of newly formulated fast-setting elastomeric impression materials. J Prosthet Dent 2005;93:530-539
36. Ferracane JL, Berge HX, Condon JR: In vitro aging of dental composites in water–effect of degree of conversion, filler volume, and filler/matrix coupling. J Biomed Mater Res 1998;42:465-472
37. Li Y, Swartz ML, Phillips RW, et al: Effect of filler content and size on properties of composites. J Dent Res 1985;64:1396-1401.