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Three-dimensional Change of Elastomeric Impression Materials During the First 24 Hours: A Pilot Study

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Clinical Relevance

Clinicians should be aware that volumetric polymerization shrinkage of elastomeric impression material continues for up to 24 hours after mixing. More accurate results may be obtained if impressions are poured as early as possible following the manufacturer's recommendations.

SUMMARY

Objectives: To evaluate the three-dimensional (3D) changes of three elastomeric impression materials using a novel measurement method for the first 24 hours after preparation.

Methods and Materials: Three impression materials consisting of a low-viscosity polyvinyl siloxane (PVS) (Aquasil LV, Dentsply Sirona, Charlotte, NC, USA) and two vinyl polyether silicone (VPES) materials consisting of a light body (EXA'lence LB, GC America, Alsip, IL, USA) and monophase (EXA'lence Monophase, GC America) materials were used in this study. All materials were prepared following manufacturer's recommendations with approximately 1-2 millimeters of material placed on the measurement pedestal of a calibrated noncontact, video imaging based, volumetric change measuring device (AcuVol ver 2.5.9, Bisco, Schaumburg, IL, USA). Data collection was initiated immediately, with measurements made every 30 seconds for 24 hours. Each material was evaluated 10 times (*n*=10). Evaluated parameters included were 24-hour mean shrinkage, mean shrinkage at time of recommended first pour, mean shrinkage between recommended first pour and 24 hours, mean maximum shrinkage, and the time of maximum shrinkage. Mean data, both within and between each group, was evaluated using Kruskal–Wallis/Dunn's tests at a 95% level of confidence (α=0.05).

Results: All three materials were found to have significant differences (*p*<0.001) in volumetric shrinkage over 24 hours. Aquasil LV and EXA'lence LB polymerization shrinkage rates were statistically similar all through the 24-hour evaluation (*p*=0.92). All three materials demonstrated similar (*p*=0.19) shrinkage between 10 and 15 minutes after preparation, while between 5 and 16 hours both EXA'lence Monophase and low-viscosity

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materials demonstrated similar polymerization shrinkage values (p=0.22). EXA'lence Monophase demonstrated significantly greater 24-hour mean shrinkage (p<0.008) as well as shrinkage between recommended first pour time and 24 hours (p=0.003) than Aquasil LV and EXA'lence LB. EXA'lence Monophase demonstrated significantly greater (p=0.002) shrinkage at the recommended time of first pour as compared to Aquasil LV and EXA'lence LB that displayed similar shrinkage (p=0.89). Furthermore, all materials demonstrated increasing polymerization shrinkage values that reached a maximum between 16 for Aquasil LV and 20 hours for EXA'lence LB, after which some relaxation behavior was observed. However, EXA'lence Monophase did not display any relaxation behavior over the 24-hour evaluation.

Conclusions: Under the conditions of this study, volumetric polymerization shrinkage was observed for one polyvinyl siloxane (PVS) and two vinyl polyether silicone (VPES) materials for up to 24 hours. All impression materials exhibited fast early volumetric shrinkage that continued past the manufacturer's recommended removal time. Dimensional change behavior was not uniform within or between groups; resultant volume change between the manufacturer recommended pouring time and 24 hours might represent up to from 20% to 30% of the total material shrinkage. It may be prudent to pour elastomeric impressions at the earliest time possible following the manufacturer's recommendations.

INTRODUCTION

Dental elastomeric impression materials should accurately reproduce intraoral features without distortion, as well as maintain a reasonable measure of stability after removal from the mouth.[1] Currently, polyvinyl siloxane (PVS) elastomeric impression materials are the predominant clinical choice for indirect restoration fabrication,[2-5] with PVS material accuracy being well described,[2-10] with some reports noting suitable linear dimensional stability for up to 14 days.[3,4,7,11] PVS materials possess equivalent accuracy as compared to digital scanning technology[7,9,12-19] but have been described as providing improved precision in situations involving multiple implant body, and dual-arch and full-arch impression requirements.[20-24] PVS elastomeric impression materials are indeed subject to dimensional changes due to time-dependent polymerization shrinkage,[3,25] constituent and product material evaporation,[11,26] as well as thermal differences between the intraoral and laboratory environment.[27-29] PVS material stability may be further challenged by impression technique, material thickness control,[28,30-32] as well as filler type and content.[33-36]

Current elastomeric impression material dental standards specify only linear dimensional stability requirements. American National Standard Institute/American Dental Association (ANSI/ADA) Specification Number 19 specifies that linear dimensional change can be no greater than 1.5%, which is usually assessed at 24 hours after preparation.[37] Accordingly, PVS linear dimensional stability has been reported.[27,38-40] However, other researchers have studied three-dimensional (3D) stability using various methods to include calculated linear measurements, photometric topographical, and microtomographic (microCT) techniques. [6,8,29,39,42] In addition, the time of stability assessments are various that have included: Immediately [27,29,40,41-45]; 1 hour[6,27,40,41]; 1.5 hours[44]; 2 hours[8]; and 24 hours[19,39,46] after preparation. To the author's best knowledge, no studies have reported real-time, 3D volumetric changes over the first 24 hours after preparation. The purpose of this study was to evaluate the real-time, 3D dimensional behavior of three impression materials utilizing a shrinkage evaluation method not previously used for elastomeric impression materials. The null hypothesis was that this methodology would find that there were no differences in the 3D dimensional stability between the impression materials being evaluated.

METHODS AND MATERIALS

The impression materials evaluated in this study were a low viscosity PVS material (Aquasil LV, Dentsply Sirona, Charlotte, NC, USA), a light body vinyl polyether silicone (VPES) material (EXA'lence LB, GC America Inc, Alsip, IL 60803 USA), as well as a monophase VPES material (EXA'lence Monophase, GC America). All the materials were prepared following manufacturer's instructions using supplied mixing tips. First, an initial amount of mixed impression material was extruded to ensure quality of mix. Next, 1-2 milliliters of material was placed on the polytetrafluoroethylene (PTFE) measurement pedestal in a calibrated (eg, gray scale and pedestal position) noncontact, video imaging based, volumetric change measuring device (AcuVol ver 2.5.9, Bisco, Schaumburg, IL, USA). Figure 1 depicts a representative image of an impression material placed on the measurement pedestal, while Figure 2 displays the measurement screen as seen on the computer monitor. The yellow line at the base of the impression material represents the pedestal outline, which was predetermined before material placement, while the green line outlines the impression material to be analyzed. Data collection was initiated immediately after placement with volume measurements made every 30 seconds for 24 hours. Each material was evaluated 10 times (*n*=10). Evaluated parameters included 24-hour mean shrinkage, mean shrinkage at the manufacturer's recommended pour time, mean shrinkage between the manufacturer's recommended pour time and 24 hours, the mean maximum shrinkage, and the time of maximum shrinkage. Furthermore, volumetric shrinkage was analyzed every minute during the first 5 minutes, followed by evaluation every 5 minutes up to 30 minutes. Mean data was found to contain abnormalities in both data distribution as well as variance homogeneity by the Shapiro–Wilk and Bartlett Test, respectively. Therefore, data was analyzed by the Kruskal–Wallis test with Dunn's post hoc analysis. All analysis was performed at a 95% level of confidence (α=0.05)

RESULTS

Comparative summary results are shown in Table 1, with mean results initially displayed every minute for the first 5 minutes. Then results are listed at 5-minute intervals until 30 minutes after preparation, followed by mean results being displayed every 30 minutes until up to 6 hours after preparation. Thereafter, hourly mean results are posted up to 24 hours. All three impression materials demonstrated significant differences in volumetric shrinkage over the 24-hour evaluation period. All three materials were hallmarked with similarity in shrinkage values; the high observed covariance undoubtedly contributed to this outcome. However, numerical trends can be observed when shrinkage change slowly subsides. This can be conjectured starting at approximately 8 hours for EXA'lence LB, 11 hours for Aquasil LV, but the EXA'lence Monophase trend requiring up to approximately 19 hours after preparation.

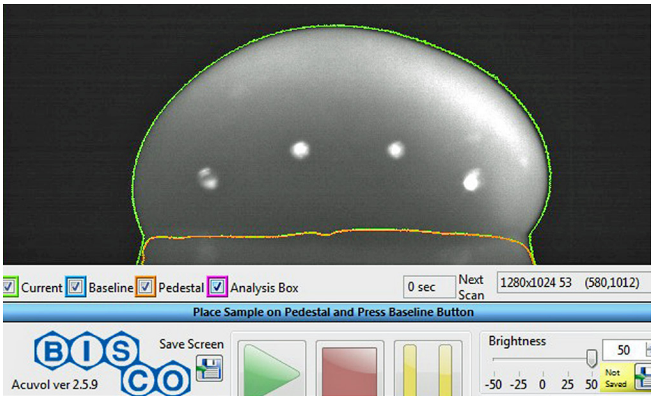
Figure 1. *Impression material placed on measurement pedestal. Impression material (green) contoured to fit on measurement pedestal (white).*

Comparison between materials found that Aquasil LV and EXA'lence LB polymerization shrinkage were statistically similar (p=0.92) all through the 24-hour evaluation. All three materials demonstrated similar shrinkage (p=0.19) between 10 and 15 minutes after preparation, while both EXA'lence viscosities had similar (p=0.22) polymerization shrinkage values between 5 and 16 hours. The mean real-time shrinkage data over the 24-hour evaluation is graphically displayed in Figure 3.

The volumetric polymerization shrinkage behavior during the first 30 minutes are detailed in Figure 4.

EXA'lence monophase demonstrated the highest initial volumetric polymerization shrinkage that transformed into a slower rate, starting approximately 8 minutes after material preparation that was observed to change to a slower rate at 12 minutes. Aquasil LV displayed a slower polymerization shrinkage change but somewhat mimicked, albeit on a lesser scale, the rate change behavior of EXA'lence Monophase. EXA'lence LB demonstrated the slowest initial polymerization shrinkage; however, this rate did not display as a dramatic rate transformation like the others but continued and surpassed Aquasil LV at approximately 15 minutes after preparation.

Afterwards, all three materials continued to demonstrate volumetric polymerization shrinkage, with maximum shrinkage occurring at approximately 16 hours after preparation with Aquasil LV exhibiting



☑ Current ☑ Baseline ☑ Pedestal ☑ Analysis Box

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Acuvol ver 2.5.9

Figure 2. *AcuVol measurement screen.*

Table 1: *Mean Shrinkage (%) with Time*[a]

Time (hours)	**Aquasil LV**	**EXA'lence LB**	**EXA'lence Monophase**
0	0.00 A	0.00 A	0.00 A
0.01 (1m)	0.08 (0.1) Aa	0.06 (0.01) ABa	0.24 (0.1) ABb
0.03 (2m)	0.16 (0.1) ABa	0.16 (0.1) ABCab	0.38 (0.2) ABCb
0.05 (3m)	0.28 (0.1) ABa	0.21 (0.1) ABCDa	0.55 (0.1) ABCDb
0.06 (4m)	0.38 (0.1) ABCDa	0.21 (0.1) ABCDEa	0.66 (0.1) ABCDEb
0.08 (5m)	0.44 (0.1) ABCDEa	0.33 (0.1) ABCDEa	0.79 (0.2) ABCDEb
0.16 (10m)	0.56 (0.1) ABCDEFa	0.51 (0.2) ABCDEa	1.08 (0.4) ABCDEa
0.25 (15m)	0.57 (0.2) ABCDEFa	0.59 (0.2) BCDEa	1.16 (0.4) BCDEa
0.5	0.62 (0.1) BCDEFa	0.73 (0.2) BCDEa	1.13 (0.4) BCDEb
1	0.65 (0.2) CDEFa	0.75 (0.2) BCDEa	1.09 (0.3) BCDEb
1.5	0.67 (0.2) DEFa	0.78 (0.2) BCDEa	1.13 (0.4) BCDEb
2	0.70 (0.2) DEFa	0.78 (0.3) BCDEa	1.08 (0.3) BCDEb
2.5	0.70 (0.2) DEFa	0.80 (0.3) BCDEa	1.12 (0.4) BCDEb
3	0.73 (0.2) DEFa	0.79 (0.3) CDEa	1.15 (0.3) BCDEb
3.5	0.75 (0.2) DEFa	0.82 (0.3) CDEa	1.15 (0.3) CDEb
4	0.75 (0.2) DEFa	0.85 (0.3) CDEa	1.20 (0.4) CDEb
4.5	0.74 (0.2) DEFa	0.86 (0.3) CDEa	1.19 (0.3) CDEb
5	0.77 (0.2) EFa	0.88 (0.3) DEFGab	1.17 (0.4) CDEb
5.5	0.77 (0.2) EFa	0.91 (0.3) DEab	1.27 (0.4) DEb
6	0.75 (0.2) EFa	0.89 (0.3) DEab	1.28 (0.5) DEb
7	0.78 (0.2) Fa	0.94 (0.3) DEa	1.35 (0.5) DEb
8	0.77 (0.2) Fa	0.99 (0.3) DEa	1.35 (0.56) DEab
9	0.78 (0.2) Fa	1.0 (0.3) Eab	1.42 (0.6) DEb
10	0.79 (0.2) Fa	1.0 (0.3) Eab	1.41 (0.5) Eb
11	0.83 (0.2) Fa	1.05 (0.3) Eab	1.40 (0.4) Eb
12	0.85 (0.2) Fa	1.01 (0.3) Eab	1.42 (0.4) Eb
13	0.84 (0.2) Fa	1.01 (0.3) Eab	1.40 (0.4) Eb
14	0.85 (0.2) Fa	1.01 (0.2) Eab	1.40 (0.4) Eb
15	0.85 (0.2) Fa	1.0 (0.3) Eab	1.43 (0.5) Eb
16	0.83 (0.2) Fa	1.0 (0.3) Eab	1.46 (0.5) Eb
17	0.82 (0.2) Fa	1.0 (0.2) Ea	1.51 (0.5) Eb
18	0.87 (0.1) Fa	1.0 (0.3) Ea	1.55 (0.5) Eb
19	0.85 (0.2) Fa	1.01 (0.3) Ea	1.64 (0.6) Eb
20	0.84 (0.2) Fa	0.96 (0.3) Ea	1.65 (0.6) Eb
21	0.84 (0.2) Fa	0.98 (0.3) Ea	1.60 (0.5) Eb
22	0.83 (0.2) Fa	0.98 (0.3) Ea	1.67 (0.6) Eb
23	0.82 (0.2) Fa	0.95 (0.3) Ea	1.65 (0.6) Eb
24	0.78 (0.1) Fa	0.93 (0.3) Ea	1.66 (0.6) Eb

[a] *Uppercase letters identify similar groups per column. Lowercase letters identifiy similar groups per row.*

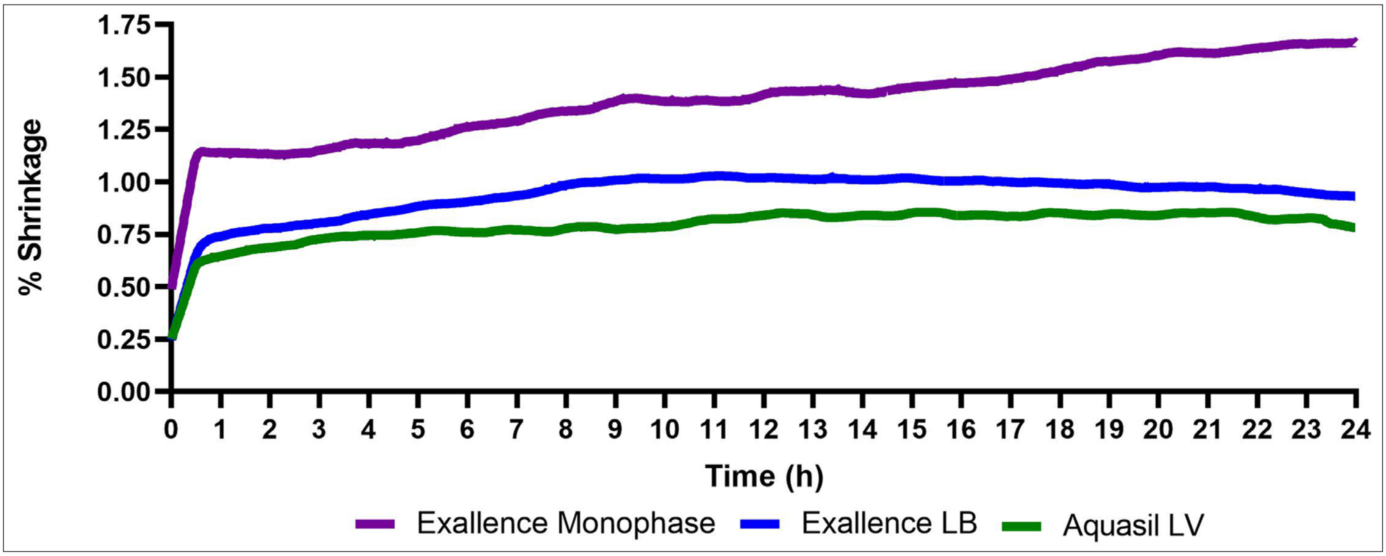

Figure 3. *Mean real time data graphs. n = 10; 0th Order Savitzky-Golay smoothing.*

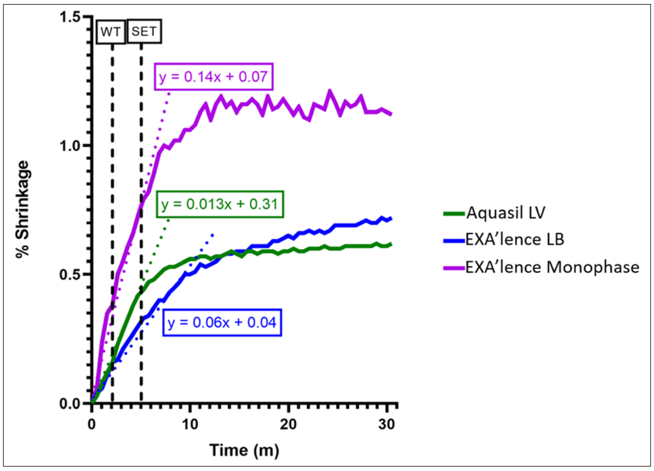

Figure 4. *Early polymerization shrinkage data (%). n = 10; raw data not smoothed. Polymerization shrinkage slope (color-coded dotted line, formula); WT = Vertical dashed line identifies end of working time for all materials; SET = Vertical dashed line identifies manufacturer's recommended removal from mouth time.*

maximum shrinkage at 16 hours after preparation, while EXA'lence LB followed suit at 20 hours. EXA'lence Monophase displayed variable behavior but did not demonstrate any relaxation over 24 hours.

The mean 24-hour polymerization shrinkage, mean polymerization shrinkage at recommended pour time, mean shrinkage between recommended pour time and 24 hours, maximum shrinkage, and time of maximum shrinkage is shown in Table 2. EXA'lence Monophase demonstrated a significantly greater 24-hour mean shrinkage ($p<0.008$) as well as shrinkage between the recommended pour time and 24 hours ($p=0.003$) than Aquasil LV and EXA'lence LB. EXA'lence Monophase demonstrated significantly greater ($p=0.002$) shrinkage at recommended time of first pour as compared to Aquasil LV and EXA'lence LB, which displayed similar volumetric shrinkage ($p=0.89$). Furthermore, EXA'lence Monophase also displayed a significantly greater mean maximum shrinkage ($p<0.002$) than the similar Aquasil LV and EXA'lence LB ($p=0.67$), but there was no significant difference in the time that the maximum shrinkage occurred ($p=0.89$).

DISCUSSION

PVS impression materials have a documented market tenure of linear dimensional stablility.[2,3,7-9,12-17] PVS base materials usually consist of a polymethyl hydrogen siloxane copolymer and an accelerator containing polydimethylsiloxane and a chloroplatinic acid metal complex catalyst.[2] Notably hydrophobic due to the aliphatic hydrocarbon chains surrounding the siloxane bond, PVS materials were modified with intrinsic surfactants,[47] ostensibly to afford better stone-pouring behavior and gypsum compatibility.[48] VPES materials were introduced as an impression material that would be intrinsically hydrophilic without added surfactants that would also provide the clinical handling of PVS materials.[11] The manufacturer reports that EXA'lence materials contain a 5%-20% polyether component, which is presumably responsible for enhancing the hydrophilicity of the impression material.[11] The PVS component in VPES materials is reported to contain both polyvinyl dimethyl and methyl hydrogen components,[11] and VPES accuracy has been reported in several studies.[11,42,44,46,49,50] It should be noted that both PVS and VPES base and accelerator pastes also contain fillers that

Table 2: *Mean Results*[a]

	Aquasil LV	**EXA'lence LB**	**EXA'lence Monophase**
Mean 24-hour Shrinkage (%)	0.76 (0.14) a	0.89 (0.2) a	1.43 (0.5) b
Mean Shrinkage at Recommended Pour Time (%)	0.62 (0.2) a	0.75 (.2) a	1.14 (0.4) b
Mean Shrinkage Between Recommended Pour Time and 24 Hours (%)	0.16 (0.1) a	0.18 (0.2) a	0.52 (0.3) b
Mean Maximum Shrinkage (%)	1.04 (0.2) a	1.19 (0.3) a	1.93 (0.7) b
Mean Time of Maximum Shrinkage (Hours)	18.1 (4.5) a	16.4 (5.4) a	—[b]

[a] *Lowercase letters denote similar groups per row (Kruskal–Wallis/Dunn's, n=10,* p*=0.05).*

[b] *Not determined.*

are added to modify handling properties, mechanical properties, and dimensional stability.[51] Depending on content and morphology, different filler materials can interface and physically interact with the impression material polymer chains, and improve mechanical properties and stability.[35,36,51,52] Furthermore, some filler materials have been reported to be surface treated to improve interactions with the polymer chains.[36] The Safety Data Sheet (SDS) does identify that Aquasil LV may contain up to 60%-70% silicon dioxide fillers,[53] while EXA'lence materials are said to contain up to 65% silicone dioxide fillers.[11] The precise etiology for the noted volumetric polymerization shrinkage difference between the two VPES materials is not precisely known, but speculatively manufacturers can manipulate both polymer molecular weight and the filler constituent to achieve the desired material mechanical properties.

Aquasil LV has a stated working time of 1 minute and 10 seconds, while both VPES materials are described to have 2 minutes of working time.[54,55] All three products are said to be ready for removal from the mouth at 5 minutes after material preparation.[54,55] As evidenced in Figure 4, all materials still experienced a considerable volumetric polymerization shrinkage at the manufacturer's recommended mouth removal time. Concern may exist with the introduction of removal distortion forces interfering with polymer chain polymerization and crosslinking. While the added effects of distortion are not fully appreciated, infrared Fourier transform spectroscopy (FTIR) evidence from Derchi and others[56] suggests that the majority of Aquasil polymer cross-linking actions has been accomplished by 300 seconds after material preparation. However, no similar studies with the VPES materials can be found in the literature.

For model fabrication, Aquasil LV is said to able to be poured with gypsum stone 30 minutes after disinfection, while it is recommended to wait up to 60 minutes for an epoxy material.[54] The manufacturer recommends that both EXA'Lence materials be poured 60 minutes after mouth removal.[55] At these recommended gypsum pouring times, all the materials are beyond the observed initial faster changes of polymerization shrinkage. However, between the manufacturer's recommended pouring time and 24 hours later, both Aquasil LV and EXA'lence LB exhibited an additional 0.16% and 0.18% volumetric shrinkage, respectively, which represents approximately 20% of the total 24-hour shrinkage for both materials. Over the same time, EXA'lence Monophase displays an additional 0.57% polymerization shrinkage, which represents over 34% of the material's total shrinkage. While all the materials were noted to exhibit continued volumetric polymerization shrinkage, demonstrated points of maximum shrinkage were observed at approximately 16 hours for Aquasil LV and 20 hours for EXA'lence LB. This volumetric shrinkage recovery occurred perhaps related to relaxation of internal stresses in the polymer network.[1] However, any reduction did not compensate to values observed at the recommended pour time. Any shrinkage recovery with EXA'lence Monophase was not observed during the 24-hour evaluation time.

The null hypothesis was rejected, as significant difference in volumetric polymerization shrinkage behavior was observed. Direct comparison with other studies describing 3D impression material shrinkage analysis is difficult due to the introduction of the technology used in this study. However, using the linear results of diameter and height change reported by Gomez-Polo and others,[40] a calculated 3D shrinkage change of a low-viscosity PVS material was approximately 0.22% between 1 and 24 hours. While this is indeed similar to that observed with Aquasil LV and EXA'lence LB in this study, the author assumes this similarity with caution, as different materials and testing methodologies were used.

Under the conditions of this study, the analysis method identified that a mean numerical 24-hour linear dimensional shrinkage assessment may not accurately reflect the dimensional change dynamics demonstrated by elastomeric impression materials. Vasiliu and others[57] noted that elastic impression material contraction was not uniform during the first 24 hours after removal from the oral cavity. Accordingly, Chandran and others[39] reported both 2D and 3D impression material shrinkage results, and found that while the materials easily met 2D linear requirements, 3D analysis identified volumetric distortion in some situations as great as 100 µm. Furthermore, Rodriguez and Bartlett [58] evaluated impression material stability, and discovered differences between linear and 3D methods, concluding that the 3D shape of a model influences impression material shrinkage over time. Levartovsky and others[59] compared linear methods and a 3D tooth-simulating model, and found that information derived from the 3D model analysis suggested that impressions derived from a one-step technique should be poured within 2 hours for the best accuracy, while materials and techniques met all linear dimensional change requirements.[59] This was reinforced by Garg and others,[60] who noted that single-step monophase viscosity impression material impressions demonstrated more distortion and suggested that pouring of the impression should not be delayed. Nassar and others[11] noted that VPES materials provided good dimensional stability over a period of time. However, 3D measurement of produced die materials suggested that the best accuracy was exhibited at the recommended immediate pour time.[11] The present study's data suggests that gypsum cast accuracy may depend on the chosen time that the impression is poured after mouth removal, as the volumetric polymerization shrinkage continued to progress with time. It may be considered prudent to pour elastomeric impression materials at the earliest possible time recommended by the manufacturer.

Under the conditions of this study, the data suggests that by delaying pouring of an impression until 24 hours after mouth removal, the continued volumetric shrinkage might afford a resultant gypsum preparation exhibiting up to 0.2% and 0.3% volume difference. Pereira and others[12] reported that a polyether material provided a gypsum die that was larger than the master die. The authors reasoned that a slightly larger indirect restoration could be advantageous as to possibly providing more space for cement.[12] However, this finding was contrasted by Emir and others,[8] who reported that volumetric changes resulted in smaller definitive casts as compared to a master model. While differences in restoration size could hopefully be reconciled with adjustment of cast metal and/or metal–ceramic crowns, evidence is emerging that identifies the importance of an accurately designed cement space with all ceramic crowns. Reports suggest possible etiology with monolithic ceramic crown clinical failures that originate from adhesive is due to radial forces that originate from adhesive cement polymerization stresses due to uneven and/or thicker adhesive resin-cement thickness between the tooth preparation and the intaglio ceramic crown surface.[61-63]

Limitations to this pilot study include the high data covariance that will be addressed in follow-up studies by using this study's data for a power analysis. Improved data acquisition with hopeful covariance reduction may also be addressed by exploring methods to reduce the impression material's surface reflectivity. Reduction of glare from the material surfaces may reduce the varied readings by the device's sensitive video camera. Furthermore, future evaluations should use material from multiple impression material cartridges to improve the number of independent samples. Linear polymerization shrinkage was not assessed for comparison and will be included in future evaluations as well as a possible control material. While this method's resultant data cannot be considered absolute, methods of calibration for this technology will be refined. Furthermore, these preliminary results may only apply to the materials tested, and should not be assumed to represent all PVS and VPES materials.

CONCLUSION

Under the conditions of this study, volumetric polymerization shrinkage was observed for one PVS and two VPES materials for up to 24 hours. All impression materials exhibited fast early volumetric shrinkage that continued past the manufacturer's recommended removal time. Dimensional change behavior was not uniform within or between groups' resultant volume change between the manufacturer's recommended pouring time, and 24 hours might represent up to 20%-30% of the total material shrinkage. Comparative literature identifies that linear polymerization shrinkage assessment methods may not accurately reflect impression material 3D dynamic shrinkage behavior. Evidence is presented that indicates it may be prudent to pour elastomeric impressions at the earliest time possible, following the manufacturer's recommendations. The clinical implications of these findings are not currently appreciated, and continued work in this area to improve the experimental technique and evaluate more impression materials is recommended.

Conflict of Interest

The authors have no financial interest in any of the companies or products mentioned in this article.

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