Dimensional stability of polyvinyl siloxane impression material reproducing the sulcular area

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The dimensional stability of a thin intra sulcular impression material reproducing the preparation finish line was evaluated. Impressions were taken of a stainless-steel master model of a simulated abutment with a 'gingival sulcus' using Express regular, Express fast and Aquasil. The putty-wash two-step technique was applied with spacer thicknesses of 0.5, 1 and 1.5 mm. Mid mesio-distal and bucco-lingual measurements were taken directly from the sulcular impression material after 0.5, 2, 24, 48 and 72 h via a Toolmaker’s microscope. The discrepancies between the measurements of the impression material and the master model were calculated. The discrepancies changed significantly over time (p<0.001). The use of a 0.5 mm spacer resulted in a negative deviation from the model (2–46 µm), minimally after 2 h. The use of 1 and 1.5 mm spacers showed a positive deviation from the model (21–52 µm) and both are equally recommended. Investment can be postponed until 72 h.

Keywords: Wash bulk, Polyvinyl siloxane, Sulcular area, Accuracy, Dimensional stability

INTRODUCTION

Impression materials are used to reproduce the form and relative positions of the teeth and the surrounding oral tissues. The accuracy of an impression material, in terms of both dimensional stability and detail reproduction, is crucial for the creation of well-fitted fixed partial dentures (FPDs). FPDs with clinically unacceptable marginal gaps retain significantly more plaque and cause higher rates of gingivitis, periodontal pockets and secondary caries compared to adequately restored teeth. The polyvinyl siloxane (PVS) (also termed addition silicone) impression materials have become extremely popular because of the combination of their excellent physical properties, good handling characteristics and almost ideal dimensional stability. Among the excellent physical properties of these materials are their high accuracy for recording fine details and the best elastic recovery of all of the available impression materials.

There are several common impression techniques for PVS of varying consistencies: the dual-viscosity one-step technique, the single-viscosity monophase technique and the putty-wash two-step technique.

The main criticism concerning the dual-viscosity one-step technique is the uncontrolled bulk of the light body whereas in the putty-wash two-step technique, the putty is applied with a spacer, followed by a light body application, thus, controlling the bulk of the wash material. Studies examining the effect of a wash bulk of PVS on the accuracy of the stone dies and/or the restoration have led to contradictory conclusions. A wash thickness of 2 mm was the most accurate for the fabrication of stone dies in some studies, while in others, a thickness of 2–4 mm or more was needed for the most accurate impressions. The accuracy of a thin wash bulk of 0.5–1.0 mm has not been reported.

PVS possess excellent dimensional stability, and thus it can be poured within 1–2 weeks after removal from the mouth. The immediate linear accuracy was reported to be influenced by the sulcular width. However, most of the previous studies did not include a sulcular area in the model around the finishing line, and thus, they did not evaluate the dimensional stability of a thin bulk of wash in the sulcular area.

The aim of this study was to evaluate the effect of spacer thickness on the accuracy and dimensional stability of a thin wash bulk of PVS in the sulcular area. The null hypothesis was that the accuracy and dimensional stability of the PVS impression material would not be affected by the spacer thickness.

MATERIALS AND METHODS

The test materials consisted of two addition cured PVS putty-wash impression systems: Express (3M ESPE, St. Paul, MN) and Aquasil (Dentsply Int., York, PA). The former included fast and regular set materials whereas the latter included regular set material only.

An aluminum rectangular-shaped master model with a rectangular space containing a removable stainless steel abutment preparation was fabricated (Figs. 1a, b). The dimensions of the abutment were 7.9 mm in length, 4.9 mm in width, 4.8 mm in height and a 3° convergence angle (Fig. 1c). This model was used as the definite standardized model for the comparison of the various impression techniques. The space around the abutment (1 mm depth, 0.2 mm width) serves as the ‘gingival sulcus’ (Fig. 1c).

Forty-five impressions were made for each
material using the putty/wash two-step technique. The
impressions were divided into 3 subgroups with spacer
thicknesses of 0.5, 1 and 1.5 mm (n=15). The spacers
were created by plastic foils with thicknesses of 0.5, 1
and 1.5 mm pressed over the metal master model using
the OmniVac technique. The thickness was verified
using a digital caliper (Mitutoyo, Tokyo, Japan). The
impressions were taken with pre-fabricated perforated
4 mm thick acrylic trays, serving as ‘stock trays’ for the
putty/wash technique, as previously described22).

All impression materials were mixed in standardized
proportions according to the manufacturers’
recommendations. The soft putty materials were weighed
(5 g of base and catalyst each) on a set of laboratory scales
and mixed with the fingertips for 45 s until the color was
uniform. The wash materials were mixed and dispensed
with an automatic gun-cartridge mixing syringe.

The preliminary putty impressions were made first
with the plastic foil on top of the master model and
allowed to set for 8 min to compensate for the difference
between room and mouth temperature11,14,23). In the
second step, the plastic foil was removed, and the wash
material was injected. The trays were seated on the
model without excessive pressure. Excess material was
vented through relief grooves. The wash material was
allowed to set for another 8 min.

The long-term accuracy of the impressions was
determined by successive measurements taken at 0.5, 2,
24, 48 and 72 h after removal from the master model. Two
measurements were taken each time at the sulcus area
of the impression material representing the mid mesio-
distal (LM) and mid bucco-lingual (NP) dimensions of
the abutment. All measurements of the impressions
were made with a Toolmaker’s microscope (TM 300,
Series No. 176, Mitutoyo, Tokyo, Japan) equipped with
a 2-dimensional data processor (Micro Pack 5 MKII,
Series 264, Mitutoyo). The measuring accuracy was
1 µm. Each measurement was taken 3 times, and the
average was considered as the representative value.
The measurements taken from the inner surface of

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Fig. 1  a: An aluminum master model containing a removable
stainless steel abutment preparation and a simulated sulcus. b:
Enlargement part of the master model containing the abutment
and sulcus. c: A schematic cross section of the model at a bucco-
lingual plane demonstrating the dimensions of the abutment
and the ‘gingival sulcus’.
the impression material at the sulcular area represent the actual coping dimensions at the finish line. These measured distances were compared to the distances between the same points on the master model, which was considered the gold standard, and the difference between them was taken as the discrepancy. Between measurements, all impressions were stored at a temperature of 22±2°C, according to the manufacturers’ recommendations.

**Statistical analysis**
The data were analyzed using a general linear model. The dependent variable was the discrepancy between the LM or NP distances of the impression material and the master model. Time (DF=4) served as the within-subjects factor. Material (DF=2) and spacer (DF=2) served as the between subjects factors. Tukey multiple comparisons were applied to test the differences between the materials as well as the between-spacer thicknesses. Each test was applied separately for LM or NP (α=0.05).

**RESULTS**
Figures 2–4 present the mean discrepancy between the impression material and the master model for the three tested materials (Express regular, Express fast and Aquasil) for the distances LM and NP. The discrepancies are presented as a function of time for each spacer thickness. The discrepancy represents the amount of inaccuracy of the impression material before pouring the gypsum. Generally, all of the impression materials showed a positive deviation, especially for spacer thicknesses of 1 and 1.5 mm, indicating that the impression was larger than the master model.

Analysis of variance with repeated measures (time=within subject factor; material, spacer thickness=between subject factors) revealed significant differences among the impression materials ($p<0.001$) and the spacer thicknesses ($p<0.001$) for each of the examined distances (LM, NP) (Table 1). The interaction between the material and the spacer was significant only for LM ($p<0.001$). The test of the influence of time is presented in Table 2 for each of the examined distances.

![Fig. 2](image1.png) The mean discrepancy (impression material minus master model) in µm (±SD) between the corresponding LM (mid mesio-distal) and NP (mid bucco-lingual) distances as a function of time for each spacer thickness for Express regular.

![Fig. 3](image2.png) The mean discrepancy (impression material minus master model) in µm (±SD) between the corresponding LM (mid mesio-distal) and NP (mid bucco-lingual) distances as a function of time for each spacer thickness for Express fast.
Each of the examined distances changed significantly over time ($p<0.001$). This change interacted with both the factors of material and spacer for the distance LM ($p<0.001$). This change interacted with either material or spacer only for NP ($p<0.001$).

Table 3 presents Tukey multiple comparison tests of the differences between the impression materials for each of the examined distances. Express fast showed the highest deviation from the model (33–64 µm) followed by Express regular (4–40 µm) and Aquasil (8–9 µm). Express fast showed a significantly higher deviation for NP and LM compared to the other materials.

Table 4 presents the Tukey multiple comparison tests of the differences between the spacer thicknesses for each of the examined distances. With spacer thicknesses of 1 and 1.5 mm, the impression deviation was positive, meaning that the impression was larger than the master model. For the 0.5 mm spacer thickness, a negative deviation of the impression was observed for LM, meaning that the impression was smaller than the master model in this dimension; however, for NP, the deviation was positive. The largest deviation was observed with the 1.5 mm spacer (37–52 µm) followed by the 1 mm spacer (23–48 µm) and then the 0.5 mm spacer (7–12 µm). For LM, the 1.5 mm spacer had a significantly higher deviation from the master model compared to the 0.5 and 1 mm spacers. For NP, there was not a significant difference between the 1 and 1.5 spacers, but there was a significant difference between them and the 0.5 mm spacer.

### DISCUSSION

The dimensional stability of elastomeric impression materials is influenced by shrinkage caused by polymerization, the byproducts of chemical reactions, thermal changes and incomplete elastic recovery from deformation, while factors such as impression disinfection, pouring time and the impression technique affect the accuracy.

The present work is one of the few studies to directly assess the accuracy and dimensional stability of a thin impression margin (1×0.2 mm) over time using a reproduction of the finish line and emergence profile on the impression material itself. This approach allowed us to avoid discrepancies that can result from the stone used, the investment expansion and metal casting shrinkage. The ‘sulcular width’ was chosen as 0.2 mm because previous studies have shown that accurate...
Table 2  Influence of time (within factor) on each of the examined discrepancies: LM (mid mesio-distal dimension) and NP (mid bucco-lingual dimension)

<table>
<thead>
<tr>
<th>Source</th>
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<th>df</th>
<th>Mean square</th>
<th>F</th>
<th>Sig.</th>
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<td>.015</td>
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<td></td>
<td>Time*material</td>
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<td>.001</td>
<td>8.873</td>
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<tr>
<td></td>
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<td>.000</td>
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<td>.001</td>
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<td></td>
<td>Error (time)</td>
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<td>512</td>
<td>.000</td>
<td></td>
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<tr>
<td>NP</td>
<td>Time</td>
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<td>.002</td>
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<td>.001</td>
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<td>Error (time)</td>
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Table 3  Tukey multiple comparison tests of the differences between the impression materials (µm) for each of the examined discrepancies: LM (mid mesio-distal dimension) and NP (mid bucco-lingual dimension)

<table>
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<th>Material</th>
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<tr>
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<td>Express regular</td>
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<td>Aquasil</td>
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<td>Express fast</td>
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<td>33.3</td>
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<td>Aquasil</td>
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<td>Express regular</td>
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<tr>
<td>Express fast</td>
<td>47</td>
<td>64.44</td>
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</table>

Table 4  Tukey multiple comparison tests of the differences between the spacer thicknesses (µm) for each of the examined discrepancies: LM (mid mesio-distal dimension) and NP (mid bucco-lingual dimension)

<table>
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<tr>
<td>LM</td>
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<td></td>
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<tr>
<td>0.5 mm</td>
<td>45</td>
<td>–7.42</td>
</tr>
<tr>
<td>1 mm</td>
<td>47</td>
<td>22.8</td>
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<td>1.5 mm</td>
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</tr>
<tr>
<td>NP</td>
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<td></td>
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<tr>
<td>1 mm</td>
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</table>

impressions can be expected only in sulci with widths greater than 0.15 mm

The results support rejection of the null hypothesis because the spacer thickness was found to have a direct influence on the accuracy and dimensional stability of the different PVS impression materials. The use of a 0.5 mm spacer resulted in more accurate impressions than 1 and 1.5 mm spacers in relation to the ‘absolute values’ of the discrepancy, while a spacer thickness of 1 mm showed better results for LM than the 1.5 mm spacer; however, in most cases, the use of a 0.5 mm spacer resulted in negative deviation from the model. The impression material in the sulcus area was much thinner relative to the bulk material possessed a sort of miniature unsupported cantilever structure. Upon removal from the sulcus, this unsupported cantilever structure could ‘flex’ outward (positive horizontal discrepancy) or inward (negative horizontal discrepancy). The range of negative horizontal discrepancies in the LM or NP dimensions was 2–46 µm (Figs. 2–4). This may cause the negative clinical outcome of an undersized casting that will produce incomplete seating with vertical discrepancy.
Among the materials tested and in all of the measured dimensions, except for Express fast in the NP dimension, a reduction in the discrepancy occurred over time, i.e., a positive deviation (generally with 1–1.5 mm spacing) will be reduced over time, and a zero/negative deviation (generally with 0.5 mm spacing) will increase in absolute value over time. This phenomenon is related to the ‘kneeling’ or collapse of the thin impression margins in the ‘dental sulcus’. Thus, limiting the time range until investment to 2–24 h will reduce the amount of the negative horizontal discrepancy to <25 µm. Typically the discrepancy tendencies of the LM (long dimension of the abutment) and NP (short dimension of the abutment) are similar. However, in the extreme unsupported cantilever structure, which was in the 0.5 mm spacer group, they behaved dissimilarly, with a slightly negative deviation in LM and a positive deviation in NP (Table 4).

Within the scope of the current research, these outcomes take into account only the dimensions of the impression material. Additional deviations that influence the final clinical results include the minimum compensatory percentage of the investment expansion (~1.2%) according to the ANSI/ADA Specification No. 228), the 20–40 µm lab spacing of the casting investment and the linear solidification shrinkage of the casting alloys (1.6–2.3%) 29). If one wishes to use a 0.5 mm spacer, for example, with a polyethylene sheet spacer alone, our clinical recommendation is to pour the impression within 2–24 h of removal from the mouth; however, if one wishes to use a 1–1.5 mm spacer, for example by temporary crowns, one can postpone the investment procedure for up to 72 h.

In the present study, there was an insignificant difference between the results obtained with 1 and 1.5 mm spacers in the NP dimension and a slightly higher discrepancy for the 1.5 mm spacer in the LM dimension. As the 1 and 1.5 mm spacers are clinically more practical compared to the 0.5 mm spacer and do not cause negative deviation, it can be concluded that they are equally recommended. Our findings are in partial agreement with the reports of Eames et al. 16), DeAraujo et al. 29) and Nissan et al. 14). These studies showed that a thicker wash bulk produced a less accurate PVS impression. Eames et al. 16) used impression trays that were fabricated with omnivac spacers of 2, 4 and 6 mm. The impressions were measured immediately after they were taken and again after 24 h. The data presented in these studies revealed that a 2 mm spacer produced the most accurate impressions. Additionally, after pouring some of the impressions, the smallest vertical discrepancy of the castings was measured when a 2 mm spacer was used. Nissan et al. 14) compared 3 different spacer thicknesses (1, 2 and 3 mm) for the production of metal castings. In this work, the impressions were poured 1 h after they were taken, and the stone dies were measured occluso-gingivally and mesio-distally. According to their results, 1 and 2 mm spacers, which were not significantly different, produced more accurate stone dies than 3 mm spacers. DeAraujo et al. 29) found that the increase in thickness of the impression material from 1 to 4 mm caused a greater distortion. Our results utilizing direct measurements of the impression material, as well as the aforementioned reports utilizing indirect measurements of the metal casting, indicate that 1–2 mm is the ideal range of spacing for producing the most accurate impressions.

When relating impression material and the NP and LM dimensions of the preparation, Aquasil showed the highest level of accuracy (≤40 µm) followed by Express regular (≤70 µm) and Express fast (≤85 µm). Moreover, Aquasil showed the best dimensional stability with only mild changes between 2–72 h.

The impressions in the current work were measured with a Toolmaker’s microscope equipped with a 2-dimensional data processor. While conventional methods for assessing the dimensional stability of impression materials are two-dimensional (2D) and assess shrinkage or expansion between selected points on the impression it can be argued that three dimensional (3D) measurements are more accurate. Chandran et al. 31), compared the two- and three-dimensional accuracy of dental impression materials. It was reported that dimensional changes observed using the 3D technique were not always apparent using the 2D technique. However, there are drawbacks associated with the 3D technique, such as the more time-consuming nature of data acquisition and the difficulty in statistically analyzing the data 31). As the main purpose of the current research was to quantify horizontal discrepancies (either positive or negative), such measurements can be satisfactorily completed with two-dimensional equipment.

For clinical practice, the results of this study must be interpreted with caution, as the in vitro model that was used only partially resembles to the biological structure of the sulcus; moreover, the temperature and humidity conditions in vivo may affect the results. Corso et al. 32) measured the dimensional stability of PVS impression materials at time intervals of 10 min to 26 h and at storage temperatures ranging from 4ºC to 40ºC. They reported that the overall dimensional changes observed were extremely small. Similarly Pant et al. 33) measured the long-term dimensional stability of four PVS duplicating materials and reported that measurements at 37ºC showed less dimensional stability than those at room temperature, but the difference was not of clinical significance. Thus, the phenomena, reported in the current work, involving the ‘collapse’ of a thin impression material in the ‘sulcular area’ over time are anticipated in vivo and warrant further investigation.

CONCLUSION

There is no difference between the use of 1 and 1.5 mm spacers, and both are equally recommended. The use of a 0.5 mm spacer produced a negative deviation, the consequence of which is vertical discrepancy after casting. To reduce that problem, the impression should be poured within 2–24 h of removal from the mouth. If using a 1 or 1.5 mm spacer, it is possible to postpone
the investment until 72 h without compromising the dimensional stability.

Aquasil showed the best accuracy for all the measurements, followed by Express regular and Express fast.

REFERENCES