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Title: Effect of simulated toothbrushing on color stability of Optiglaze Color in vitro

Running Title: Effect of toothbrushing on color stability of Optiglaze

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ABSTRACT

Purpose: The purpose of this study was to investigate the color change (∆E) of Optiglaze Color applied onto bisacryl and polymethyl methacrylate after 15 years of simulated toothbrushing.

Materials and Methods: Bisacryl shade A1 was injected into a mold and polymethyl methacrylate shade A1 was milled to form discs that were 12 mm in diameter and 2 mm thick. Forty-two discs were fabricated and divided into two groups of 21 discs based on material. Optiglaze Color in the olive shade was applied to the discs according to the manufacturer's instructions. Optiglaze Clear was applied to one disc from each group as the control. Each material group was then randomly subdivided into two more groups consisting of 10 discs each based on the media used during toothbrushing simulation. Toothpaste was used as the brushing media for one group and distilled water for the other group. A novel 10-station toothbrushing simulator was used to brush each disc in 3-hour intervals for a total of 15 hours for each disc. The unstained control was measured and stored within the spectrophotometer for direct comparison with all other discs of the same material. This process was completed for each material at baseline and after 3, 6, 9, 12, and 15 hours of toothbrushing. The change in ∆E was then calculated from the baseline ∆E to the 15-hour ∆E.

Results: The average change in ∆E after 15 years of simulated toothbrushing was 2.22 for the polymethyl methacrylate-toothpaste group, -0.02 for the polymethyl methacrylate-water group, 3.87 for the bisacryl-toothpaste group, and 0.66 for the bisacryl-water group. The endpoint ∆E of the toothpaste groups were significantly different from the water groups ($p<0.001$). The change in ∆E from baseline to 15 years was acceptable in all groups and perceptible only in the toothpaste groups when compared to the acceptability and perceptibility thresholds of 3.7 and 1.7 ∆E, respectively.

Conclusions: Optiglaze Color demonstrated excellent color stability when brushed with water only and clinically acceptable color stability when brushed with an abrasive toothpaste when used with both bisacryl and polymethyl methacrylate restorative materials. The change in color was acceptable and imperceptible up to 6 years for bisacryl and 12 years for milled polymethyl methacrylate when brushed with an abrasive toothpaste. Toothbrushing with water had no effect on Optiglaze Color up to 9 years for bisacryl and 15 years for milled polymethyl methacrylate.

KEYWORDS: bisacryl, PMMA, toothpaste, ∆E, perceptibility, acceptability

INTRODUCTION

Custom characterization is a priority in esthetic dentistry. In certain clinical situations, acrylic dentures and provisional crowns may require custom characterization. Optiglaze Color is a light-cured characterization system that can be used to stain and glaze composite, polymer-infiltrated ceramic network, polymethyl methacrylate (PMMA), and bisacryl materials to satisfy the high esthetic demands of modern dentistry. The product claims long term wear resistance and color durability including surface gloss due to its nano-filled technology. A review of the literature reveals sealing restorations with this material is beneficial for maintaining a smooth surface texture and preventing uptake of surface stains,[1] but the longevity of the color component has not been reported. It is unknown how long this material will maintain its color stability over time when subjected to regular toothbrushing necessary to maintain oral health.

In complex oral rehabilitation, provisional restorations can be worn by patients for several months. Bisacryl is a widely used material to fabricate provisional restorations. However, their esthetics can sometimes be compromised due to a narrow shade selection and single opacity of the material. In the case of a single provisional crown, it may be difficult to color match the provisional crown with the existing natural dentition. Custom characterization of provisional crowns can offer improved esthetics and is only required for a relatively short period of time.

In the fabrication of removable complete and partial dentures, clinicians have commonly adopted the use of PMMA denture teeth to replace missing teeth. Esthetics of denture teeth can vary depending on the manufacturer and cost. It can also be challenging to match denture teeth to the patient's natural dentition for removable partial dentures. In addition to denture teeth, PMMA is often used with digital applications to provisionalize implant supported partial- or full-arch fixed prostheses where the gingiva and teeth are milled from a monolithic puck which lacks the characterization found in denture teeth. The ability to characterize PMMA can be a valuable option to improve esthetics in many clinical applications.

Shade matching is based on value, chroma, and hue. Conventional shade matching uses a shade guide to subjectively identify the shade of the patient's natural teeth. Shade matching using an instrument such as a spectrophotometer or colorimeter proves to be a more dependable method of shade selection due to its ability to quantify color.[2,3] The difference in color between two objects can be measured objectively by a calculation that determines the ΔE, or the distance between two colors in three dimensions.[4] The International Commission on Illumination (CIE) defines the CIELAB color system formula as:

$$\Delta E^*_{ab} = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2} \quad \text{OR} \quad \Delta E^*_{ab} = [(\Delta L^*)^2 + (\Delta C^*_{ab})^2 + (\Delta H^*_{ab})^2]^{1/2}$$

The L^* coordinate represents lightness or darkness, the a^* value represents red or green, and the b^* value represents yellow or blue. In the alternate formula, the C^*_{ab} value represents chroma and the H^*_{ab} value represents the hue.[4]

The Vita EasyShade 4.0 is a dental spectrophotometer which measures the wavelengths of light reflected from an object and records the amount of visible radiant energy for value, chroma, and hue present in the visible spectrum.[5,6] It can measure the color difference between two objects according to the CIELAB color system (reported as ΔE_{ab}) when used in the comparison mode.

The ΔE between the shade of a restoration and the natural dentition can be evaluated to determine the clinical relevance of the shade mismatch using known visual acceptability and perceptibility thresholds. The 50:50% acceptability threshold (AT) means that 50% of observers find a level of color difference as acceptable and the other 50% as not acceptable. The 50:50% perceptibility threshold (PT) means that 50% of observers reported a certain amount of color difference as perceptible and the other 50% as not perceptible.[7] Visual acceptability is more important than perceptibility.[7] The values for these thresholds vary widely due to their subjective nature and difficulty to establish.[3] In addition, these values are dependent on the formula used by the spectrophotometer. For CIELAB formula, the AT 50:50% is 3.7 ΔE_{ab}, and the PT 50:50% is 1.7 ΔE_{ab}.[7]

PMMA is a widely used dental restorative material and comes in many forms. Its traditional form requires laboratory or chairside mixing of a methacrylate monomer and polymethyl methacrylate polymer with various forms of activation of the polymerization reaction. It is inexpensive, strong, and can be highly polished, but some disadvantages associated with this form of PMMA are its exothermic reaction and polymerization shrinkage.[1] Using digital technology, PMMA can be milled from a very dense pre-polymerized puck. In this form, there is no polymerization shrinkage, exothermic reaction, free monomer, or porosity.

Bisacryl composite is a popular provisional restorative material due to its ease of use, minimal shrinkage, improved esthetics, and greater wear resistance when compared to PMMA. It is a self-curing BIS-GMA resin with added methacrylate and is composed of a base and catalyst. However, its use is limited to single units and 3-unit FDPs due to its inferior strength compared to PMMA, and it is considerably more expensive.[8]

In vitro dental research involving toothbrushing simulation is frequently reported in the literature. The toothbrushing parameters applied vary widely based on the study. The force applied at the toothbrush head varies from 2-4N[9-12] and 200-450g.[13-16] The liquid media used for the simulation is commonly a slurry consisting of toothpaste and water with the most common ratio being 1:1. However, a 1:2 toothpaste:water ratio has also been used.[13] The toothpaste chosen for testing usually has a high relative dentin abrasion (RDA) value defined as >100.[13]

Correlating time under in vitro simulated toothbrushing to clinical toothbrushing time is inconsistently reported as either strokes per year or time equivalent per year.[13] One year of clinical toothbrushing has been equated to anywhere from 7,000[17]-23,000[18] strokes, or to as little as 10 minutes[9] to as much as 24 hours[11] of continuous toothbrushing simulation. The diversity is likely due to the dissimilarity in toothbrushing simulator designs and the logic applied when calculating the equivalent number of strokes or time under simulation to clinical relevance.

In the present study, a novel toothbrushing simulator was designed and constructed based on previously reported parameters. A force of 2N (208g) was applied to each toothbrush head. A high RDA value (200) toothpaste was used in a 1:2 ratio of toothpaste to water. The time equivalent from simulation to clinical toothbrushing was limited to time rather than strokes due to the use of electric toothbrushes in the simulator.

The calculation of the time equivalent was based on the average surface area of coronal tooth structure in the oral cavity (42.8 cm^2)[19] and assuming thrice daily toothbrushing for two minutes (360 seconds) or 2,190 minutes per year. The surface area of the discs used in this study was 1.13 cm^2, which is equivalent to approximately 3% of the average surface area of all teeth combined in the oral cavity.. Based on these numbers, 66 minutes is equivalent to 1 year of clinical toothbrushing when the surface area of the discs is considered. For ease of calculation and simulation, 1 hour of simulation was equated to 1 year of clinical toothbrushing for the design of the present study.

The harsh oral environment can present a longevity challenge for most dental restorative materials. Previous studies show that Optiglaze Clear can withstand thermal cycling[20] and prevent uptake of surface stains.[1] Optiglaze Clear has been evaluated in these studies but not Optiglaze Color. Oral hygiene procedures have been shown to cause wear of many ceramic stains and restorative materials, especially when exposed to abrasive toothpaste.[10,11,13] On the other hand, the effect of oral hygiene procedures on light cured stains has not been investigated.

Therefore, the purpose of this study was to investigate the color change (ΔE) of Optiglaze Color applied onto bisacryl and PMMA when subjected to 15 years simulated toothbrushing with either toothpaste or water. The null hypotheses were that time will have no effect on ΔE, there will be no difference in ΔE between PMMA and bisacryl, and there will be no difference in ΔE between toothpaste and water.

MATERIALS AND METHODS

A power analysis was performed using software (Microsoft Excel) based on a preliminary pilot study to determine the number of discs for each group. The statistical power was set at 80%, the significance level was 0.05 (alpha), the standard deviation of the pilot study was 0.42 ΔE, and the effect size was set at 0.5. This yielded a sample size of 8.7. A sample size of 10 was selected to account for potential outliers.

Forty-two discs (12x2 mm) were fabricated; 21 discs each with bisacryl and PMMA. Each material group was then further subdivided into 2 groups consisting of 10 discs each based on the media used during toothbrushing simulation. Toothpaste (Sparkling White Cinnamint, Colgate-Polmolive, New York, NY) was used for one group and distilled water was used for the other group. The four groups consisted of bisacryl brushed with water (BW), bisacryl brushed with toothpaste (BT), PMMA brushed with water (PW), and PMMA brushed with toothpaste (PT).

Optiglaze Color shade olive was applied to the discs according to manufacturer's instructions. Each disc was air abraded with 50 micron aluminum oxide particles at 1.5 bar at a distance of 10 mm for 5 seconds. The discs were steam cleaned and dried. Care was taken to apply Optiglaze Color evenly to each disc. The bottle of Optiglaze Color was shaken for 10 seconds and one drop was dispensed into a well. A clean microbrush applicator was used to apply an even coat of stain to the surface of each disc. A halogen curing light (Coltolux 75, Coltene/Whaledent, Cuyahoga Falls, OH) was used to cure each disc for 40 seconds. The curing light was tested once prior to curing the discs with an analog radiometer (Litex Industries, Mooresville, NC) revealing an output of 600 mW/cm^2 which is above the minimum standard of 300 mW/cm^2.[21] The discs were then cured with a laboratory curing light (Labolight Duo, GC America, Alsip IL) for 90 seconds to ensure a complete and uniform cure. The discs were initially compared to a stained control with a spectrophotometer (Easyshade 4.0, Vita Zahnfabrik, Bad Sackingen, Germany) to ensure homogeneity of the baseline ΔE within each group. Discs were rejected if the ΔE was greater than ±0.5. Optiglaze Clear was applied to one disc from each group to serve as the unstained control. Materials used in this study are summarized in Table 1.

All discs were then organized and stored in 3D-printed trays (Figure 1). The discs on the left side of the tray were used in the toothpaste simulation and those on the right side were used in the water simulation. The controls were placed at the top of their respective trays. The trays were fabricated with a lid to aid in consistent measuring with the spectrophotometer (Figure 2). The back of the discs were engraved with identification markings consisting of the group name (BW, BT, PW, or PT) and a numeral (1-10).

A novel toothbrushing simulator was constructed (Figure 3). Ten battery-operated toothbrushes (Spinbrush, Arm & Hammer, Ewing Township, NJ) were suspended with a heavy elastic band allowing the toothbrush to pivot. The brush heads were altered so that all bristles contacted the discs evenly. The brush heads' forward and backward linear motion measured 4 mm unidirectionally. Each disc was held in place by a custom-designed 3D-printed well (Figure 4). The wells were designed with a curved bottom to contain the toothpaste slurry or water so that the discs remained submerged in the brushing media. A force of 2N (208g) was applied at the brush head using a 3D-printed tray designed to hold coins as an adjustable weight to complement the pivoting suspension of each toothbrush. A digital scale (FZ-1000, Fuzion, Barcelona, Spain) was placed underneath each well to determine the correct amount of coins required to apply a force of 2N to each disc.

Toothbrushing simulation was performed in 3-hour intervals for a total of 15 hours for each group. For the toothpaste groups, a slurry of toothpaste and water (1:2) was mixed and ¼ teaspoon was dispensed into each well. The PMMA discs were always brushed with stations 1-5 and the bisacryl discs with stations 6-10 of the toothbrush simulator.

Due to the unidirectional movement of the brush heads, the wells were rotated 120 degrees each hour of simulation so that each disc was brushed in 3 intersecting directions during each 3-hour interval. At the same time, the scales were also checked and the weight was adjusted as needed to maintain a force of 2N throughout the simulation. After each 3-hour interval, the toothbrush batteries were replaced, the toothpaste slurry or water was changed, and the scales were calibrated using a known weight of 240g.

The discs were removed from the wells, rinsed, dried and placed into their respective trays for measurement with the spectrophotometer. The lid of the trays oriented the tip of the spectrophotometer to the center of each disc for a repeatable measurement position at each interval (Figure 3). The measurements were made in a controlled lighting environment. A room with no windows and no overhead lighting was used with a laptop on the lowest brightness setting as the only light source. The trays were placed in the same location with respect to the laptop and on a white background for each interval measurement.

The spectrophotometer was calibrated prior to each round of measurements. The control was measured with the spectrophotometer and the value was stored within the device for direct comparison with all other discs of the same material. The output ΔE between the unstained control and each stained disc was recorded three times consecutively then averaged. This process was completed for each material at baseline and after 3, 6, 9, 12, and 15 hours of toothbrushing. The change in ΔE was then calculated from the baseline to the 15-hour ΔE for each disc.

RESULTS

The mean and standard deviation of the change in ΔE from baseline to 15 hours were plotted by group (Figure 5). Generally, the toothpaste groups displayed greater variance compared to the water groups. Two outliers were identified. One from the PT group was identified as a statistical outlier using the ROUT algorithm (Q=1%). One from the BT group was identified due to a malfunction of the toothbrush head during the first interval of testing, and the entire toothbrush assembly at that station was replaced after the 15-hour testing period and prior to beginning the next group. However, this disc did not emerge as a statistical outlier likely due to the BT group showing the highest variance. Removal of the outliers resulted in four datasets that passed the D'Agostino and Pearson omnibus normality test and the Shapiro-Wilk normality test ($p \geq 0.16$) and also passed the Brown-Forsythe test for homogeneity of variance ($p=0.089$). Two other outliers were evaluated in the BT group which had the highest variance. After further analysis, the two discs were categorized into a subgroup with a more rapid decay pattern rather than excluding the data from statistical analysis. The mean and standard deviation of the finalized datasets are represented in Figure 3.

The baseline values were analyzed using the Tukey's multiple comparisons test showing no significant difference between PT and PW ($p=0.998$) or BT and BW ($p=0.297$), but did find a significant difference between the two materials consistent with the shade difference between the two materials. This was accounted for by the use of two unstained controls, one for each material.

The datasets were plotted over time (Figure 6). The PT, PW, and BT groups fit a linear model (CI=95%) with significantly different slopes according to both one-way ANOVA and Tukey's multiple comparisons test ($p<0.001$). The BT subgroup showed a one-phase exponential decay pattern and more rapid change compared to the BT group. The BW group fit a segmental linear regression with the junction at the 9-hour time point. The PW and BW groups showed no change in ΔE over time up to the 1- hour and 9-hour time points respectively.

The endpoint ΔE of each group after 15 hours of toothbrushing were compared using a one-way ANOVA. There were significant differences between the mean group values ($p<0.001$). Tukey's multiple comparisons test showed no significant difference between PT and BT or between PW and BW. However, PT and BT were significantly different than PW and BW.

All null hypotheses were rejected except in the case of the PW group, where time had no effect on ΔE.

The change in ΔE after 15 hours of toothbrushing was also compared to the perceptibility and acceptability thresholds. There was a statistically significant difference between the toothpaste and water groups when compared to the perceptibility threshold. The average change in ΔE of the water groups

(PW and BW) were not perceptible after 15 hours. However, the average change in ∆E of the toothpaste groups (PT and BT) were perceptible after 15 hours. All groups had an acceptable change in ∆E after 15 hours. A one-tailed T test (a=0.05) was used to analyze the change in ∆E compared to the 50:50 perceptibility and acceptability thresholds of 1.7 and 3.7 respectively (Table 2).

DISCUSSION

The color change of the Optiglaze Color based on material and brushing media is of clinical significance. First, the change in ∆E was considered acceptable in all groups from baseline to 15 years simulated toothbrushing. The change in ∆E was only perceptible when an abrasive toothpaste was used during the simulation. This demonstrates excellent wear resistance of Optiglaze Color within the limitations of this in vitro study. The use of an abrasive toothpaste is generally discouraged for removable prostheses, but should be further emphasized if Optiglaze Color is used to characterize a final prosthesis such as denture teeth or a denture base. The use of water as the brushing media had no effect on PMMA, and only a slight effect on bisacryl even after 15 years of simulated toothbrushing.

The PMMA discs have the same basic molecular structure as Optiglaze Color (MMA) which likely contributed to a smaller change in ∆E and better wear resistance due to the chemical bond between the materials in addition to the micromechanical bond. Bisacryl discs exhibited a larger change in ∆E likely due to the decreased bond strength to the Optiglaze Color because the materials are molecularly dissimilar, and only a micromechanical bond can be formed between the two materials.

The clinical significance of time varies based on the material since PMMA is often used as a definitive restorative material and bisacryl is rarely used for more than 1 year. The average change in ∆E was not perceptible in the BT group (∆E=1.2) after 3 years of simulated toothbrushing when compared to the 50:50 perceptibility threshold (∆E=1.7). Therefore, the difference between the PT and BT groups is minimized with respect to clinical significance since bisacryl is manufactured as a short-term restorative material. The average change in ∆E was not perceptible in the PT group (∆E=1.5) after 9 years of simulated toothbrushing when compared to the 50:50 perceptibility threshold (∆E=1.7) which falls well within the clinical lifespan of a removable prosthesis.

The in vitro design of this study was the primary limitation. In addition, no thermal cycling or acidic liquids were used to further simulate the conditions of the oral environment. This was done so that the effect of toothbrushing alone could be studied. Future research could incorporate those additional variables or other materials in combination with Optiglaze Color such as polymer infiltrated ceramic network, conventionally processed PMMA denture base, prefabricated PMMA denture teeth, and 3D-printed resins.

CONCLUSIONS

Optiglaze Color demonstrated excellent color stability when brushed with an abrasive toothpaste within the parameters of normal clinical use of both bisacryl and milled PMMA materials. The change in color was acceptable and imperceptible up to 6 years simulated toothbrushing for bisacryl and 12 years of simulated toothbrushing for milled PMMA when brushed with an abrasive toothpaste. Toothbrushing with water had no effect on Optiglaze Color up to 9 years simulated toothbrushing for bisacryl and 15 years for milled PMMA.

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Table 1: Materials tested in the present study.

Material	Manufacturer	Type	Component	Filler	Shade
Optiglaze Color	GC America, Alsip, IL	Nano-filled glaze system	PMMA, MMA	Silica	Olive
TempFix	Harvest Dental, Brea, CA	PMMA	PMMA (pre-polymerized)	none	A1
ProTemp Plus	3M ESPE, St Paul, MN	Bisacryl Composite Resin	Ethanol,2,2'-[(1-methylethylidene)bis(4,1-phenyleneoxy)]bis-, diacetate, benzyl-phenyl-barbituric acid, tert-butyl peroxy-3,5,5-trimethylhexanoate.	Silane-treated silica	A1

Table 2: Averaged ∆E values for each group at baseline, after 15 hours of toothbrushing simulation, and the change in ∆E. The slope of the line of best fit if a linear regression was applied. Acceptability and perceptibility threshold outcomes.

* One-phase exponential decay pattern

† 0-9 hour segment

‡ 9-15 hour segment

Group	Baseline ∆E ±SEM	15hr ∆E ±SEM	Change in ∆E ±SEM	Slope (∆E/hr)	Outcome AT 50:50	Outcome PT 50:50
PT	7.05 ±0.10[a]	4.86 ±0.23[a]	2.22 ±0.15[a]	-0.15[a]	Acceptable ($p<0.001$)	Perceptible ($p=0.008$)
PW	7.07 ±0.07[a]	7.09 ±0.13[b]	-0.02 ±0.09[b]	0.00[b]	Acceptable ($p<0.001$)	Not perceptible ($p<0.001$)
BT	7.56 ±0.10[b]	4.25 ±0.24[a]	3.48 ±0.2[c]	-0.22[c]	Acceptable ($p=0.6205$)	Perceptible ($p=0.001$)
BT subgroup	7.37 ±0.33[b]	2.03 ±0.63[c]	5.33 ±0.37[d]	N/A*	Not evaluated	Not evaluated
BW	7.85 ±0.16[b]	7.19 ±0.15[b]	0.66 ±0.13[e]	-0.01[†b] 0.11[‡a]	Acceptable ($p<0.001$)	Not perceptible ($p<0.001$)

Figure 1: (BOTTOM) 3D-printed tray with discs organized into their respective wells. Note the unstained control located at the top of the tray. (TOP) Lid that fits over trays with indexes to center the holes over the discs.

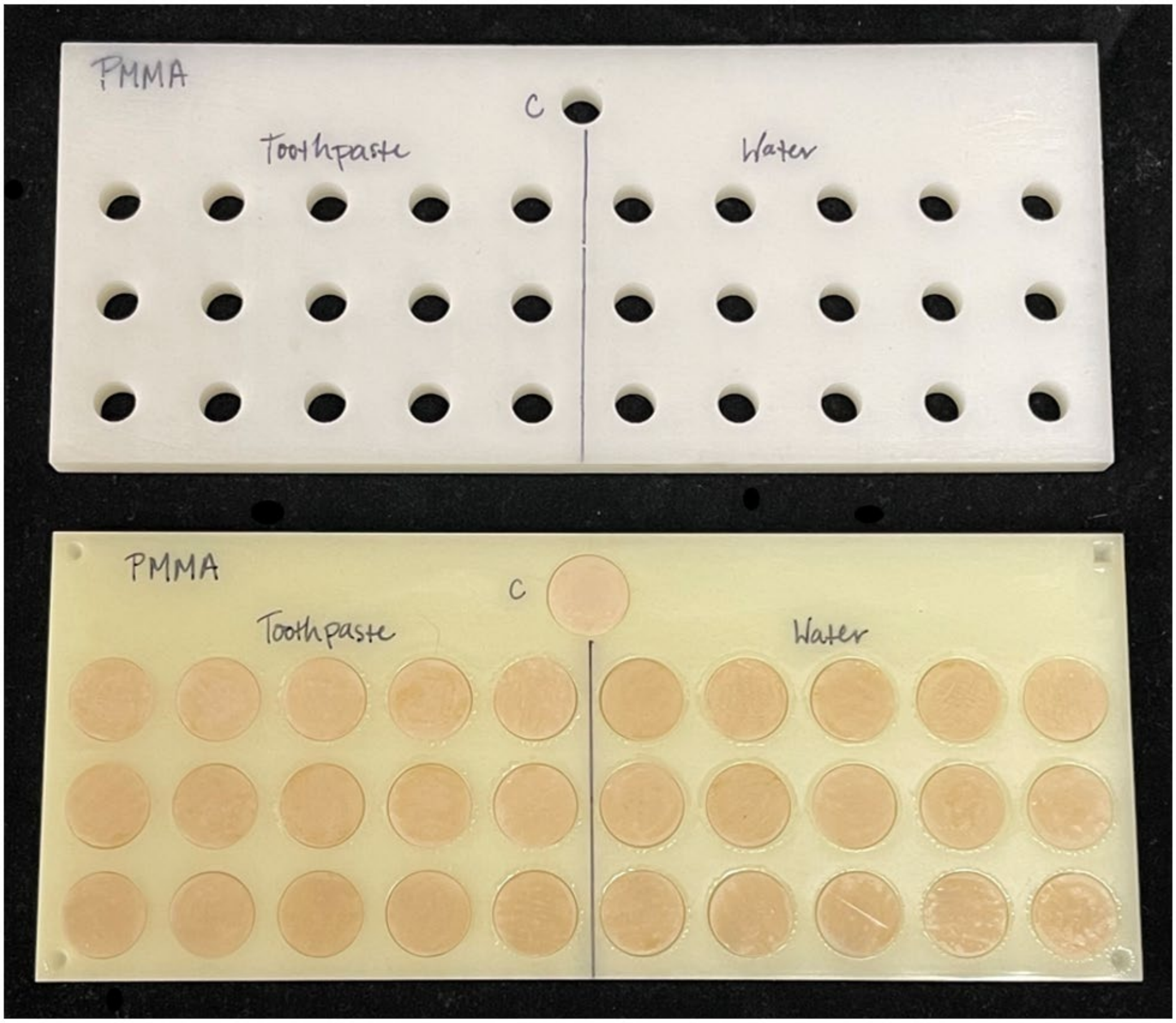

Figure 2: Tip of spectrophotometer inserted into 3D-printed tray with lid in place for consistent orientation onto the center of each disc during repeated measurements.

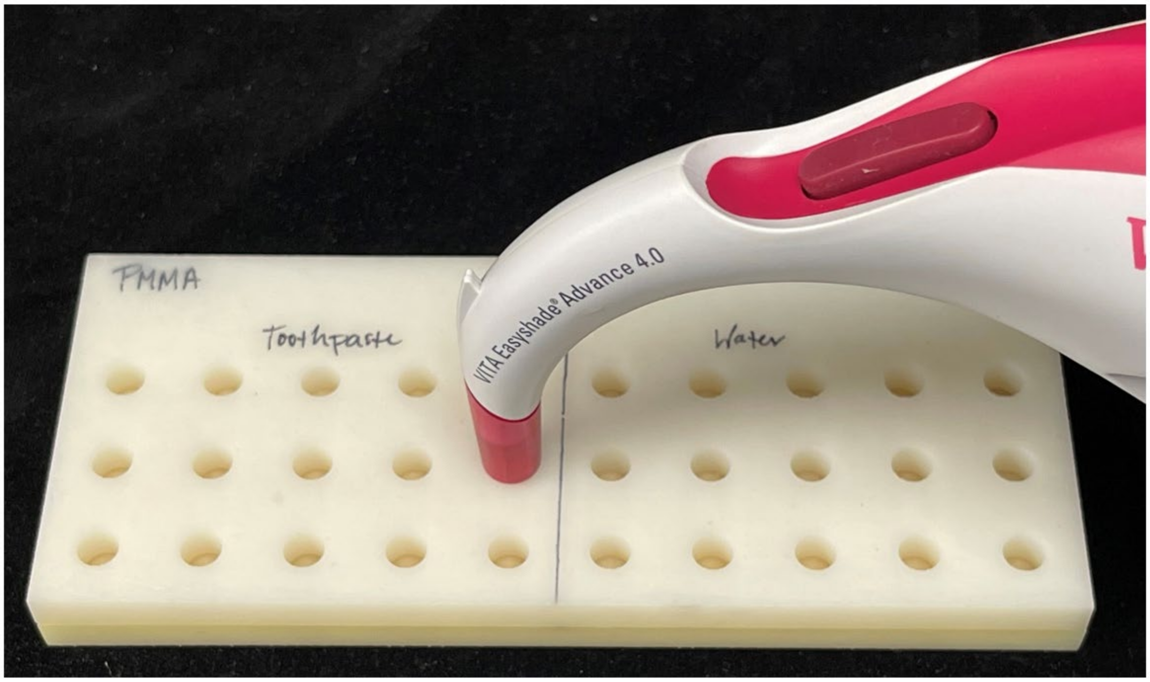

Figure 3: (A) 10-station toothbrushing simulator; (B) Single toothbrush assembly components.

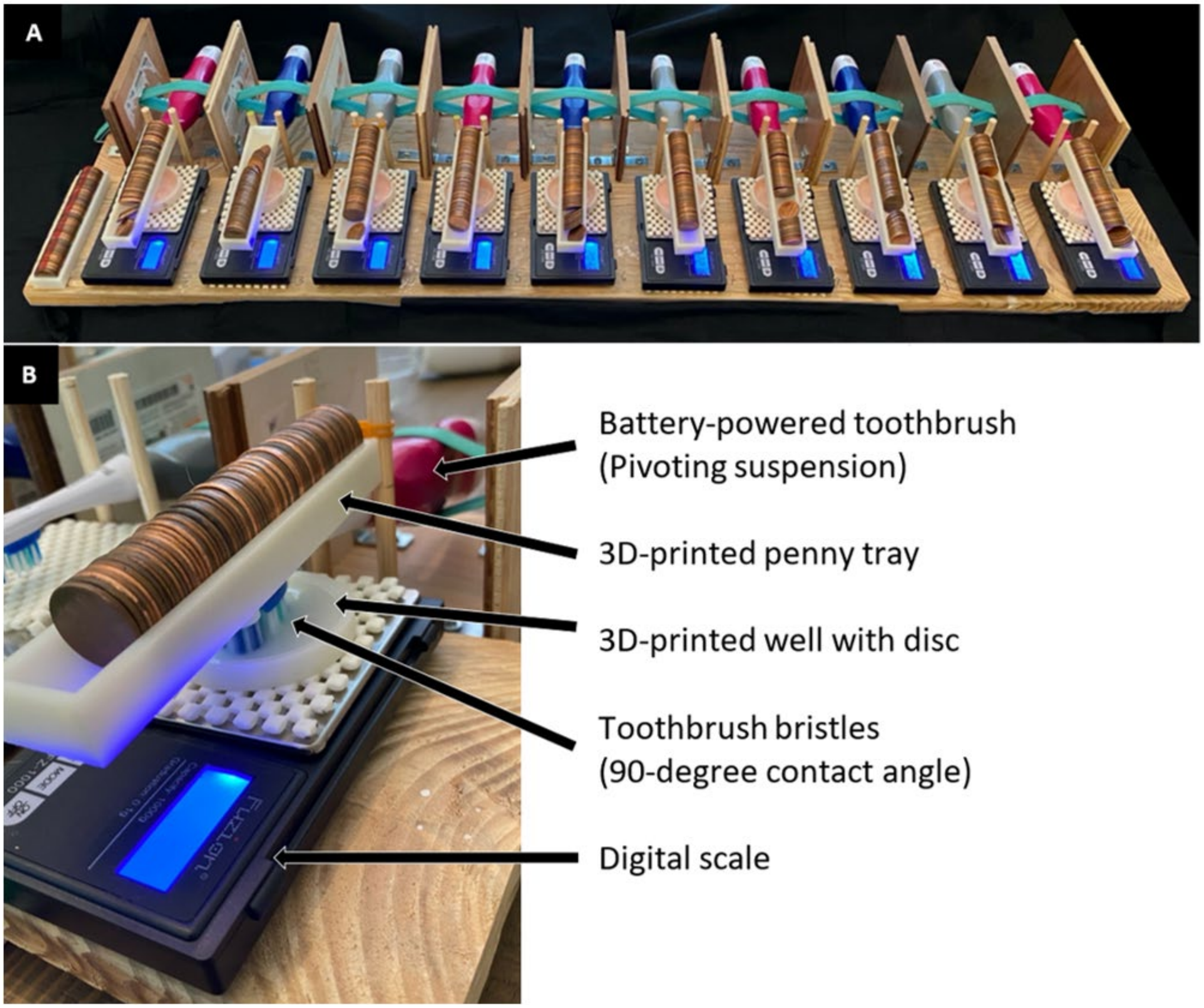

Figure 4: 3D-printed well design adapted by 3D Medical Applications Center, Walter Reed National Military Medical Center. The curved internal surface allowed the brushing medium to remain over the disc during simulation. The disc fit precisely so that the glazed surface was flush with the internal surface of the well.

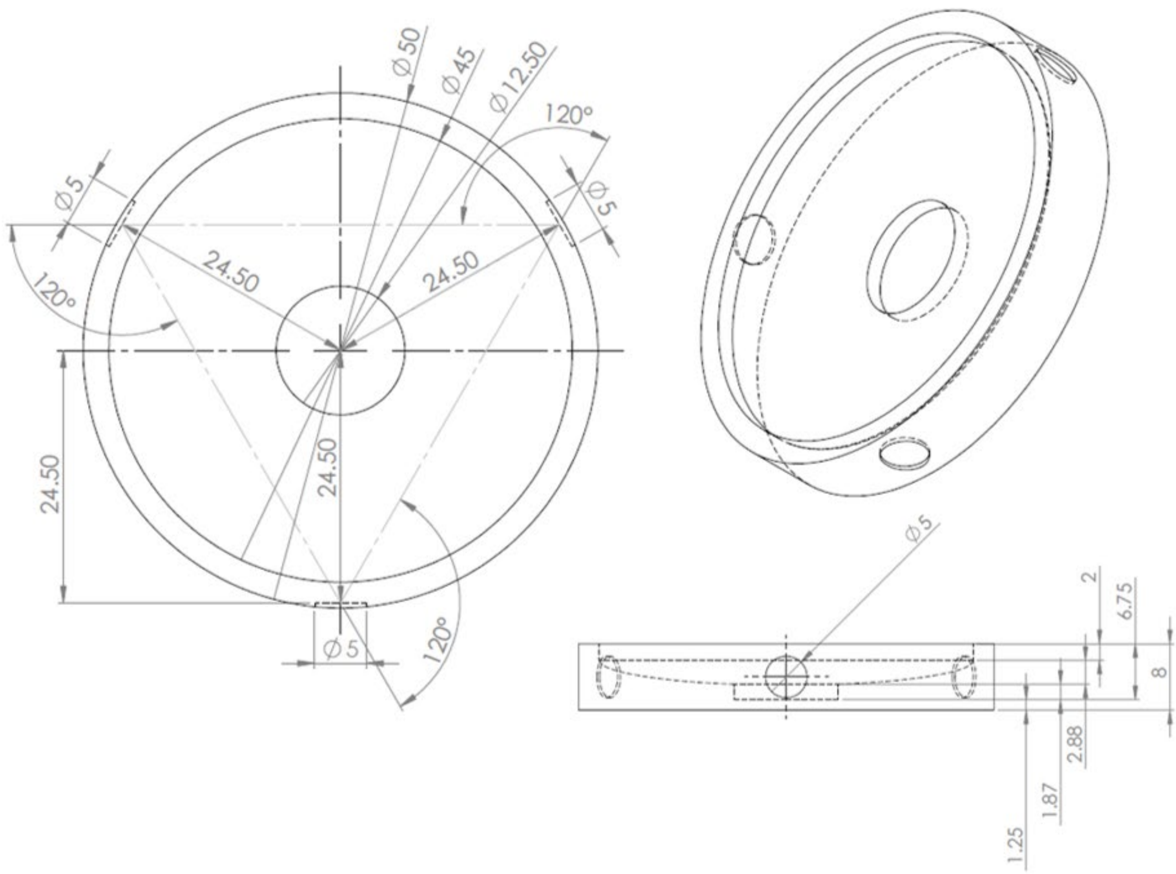

Figure 5: Total change in ∆E from baseline to 15 hours for all 40 discs organized by group.

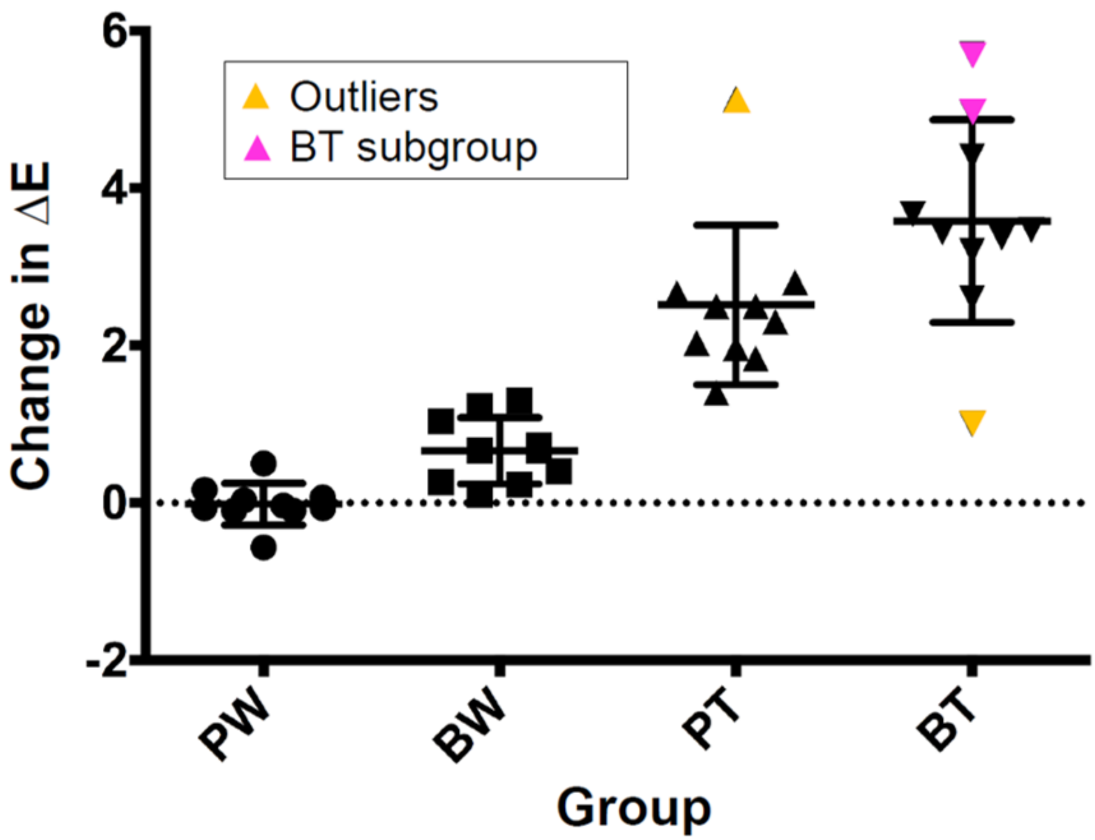

Figure 6: Average change in ∆E over time. Each point represents the average of all 10 discs per group at the given time point. The black lines represent the statistical model applied to each group.