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ORIGINAL RESEARCH

Employment of Reservoirs in At-Home Whitening Trays: Efficacy and Efficiency in Tooth Whitening

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ABSTRACT

Aim: This study aimed to determine the efficacy of trays made with and without reservoirs, in conjunction with time and cost evaluations, by measuring color change with home whitening procedures.

Materials and methods: Extracted human maxillary teeth (central incisors n = 20; canines n = 20; molars n = 20) and 60 artificial teeth (lateral n = 20; premolar n = 40) were mounted into ten typodonts. Tray fabrication was completed such that a block-out resin reservoir was placed on half of the buccal surface of the tray, while the other half remained without a reservoir. Whitening with custom fabricated trays was performed based on two different whitening regimens, where each regimen was assigned to five typodonts: Night-time: Opalescence PF 10% carbamide peroxide for 8 hours daily and Day-time: Philips DayWhite 9.5% hydrogen peroxide for 30 minutes, twice daily. Both systems were applied for 1 week. To evaluate tooth shade, the VITA Easyshade® Advance 4.0 spectrophotometer was used. Color measurements were obtained at baseline (T_1), 1-day post-whitening (T_2), and 1 month post-whitening (T_3). One-way ANOVA, followed by post-hoc Tukey's HSD test, was used to detect significant difference in the overall color change (ΔE^*) among the four groups at T_2 and T_3. Additionally, paired-sample t-test was used to assess difference in ΔE^* between T_2 and T_3 treatment within each of four techniques of tray fabrication.

Results: No significant difference in ΔE^* was found among the four groups at T_2 and T_3 ($p > 0.05$ in each instance). There were significant differences in mean ΔE^* between T_2 and T_3 treatment for the day white treatment groups without reservoir (6.96 *vs* 10.19 respectively; $p = 0.0026$) and with reservoirs (6.23 *vs* 9.79 respectively; $p = 0.0031$).

Conclusion: The use of reservoirs does not have a significant effect on whitening efficacy, regardless of type of whitening material and regimen.

Clinical significance: The use of custom fabricated trays with or without reservoirs were equally effective in whitening teeth.

Keywords: Custom fabricated tray, Reservoir, Tooth color change, Tooth whitening.

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INTRODUCTION

The expansion of esthetic-based dentistry remains persistent as it continues to parallel vigorous media emphasis on beauty and health. Since, its introduction to scientific literature in 1989, at-home whitening with the use of custom fabricated trays has resounded across the nation.[1] Data accumulated over the last 20 years, including some long-term clinical study follow-up that support the efficacy and also indicate nonsignificant and long-term oral or systemic health risks associated with at-home whitening materials containing 10% carbamide peroxide under the proper supervision of the dentist.[2-4]

The custom fabricated tray used by patients is a fundamental element in at-home whitening treatment and is a determinant of the procedure's success. Current protocol for fabrication of tooth whitening trays incorporates the hand-placement of block-out resin reservoirs on the cast models to create an additional space between the tray and the teeth. The additional space still used today and

properly termed a 'reservoir' which is intended to permit an additional amount of bleach to contact the teeth. The reservoir ceases immediately above the gingival line; this is thought to prevent excess flow of bleach out of the tray and onto the gingiva, which would cause gingival inflammation upon excess exposure.[5] An additional argument for the presence of the reservoir includes its potential role in bleach distribution. This rationale claims the reservoir aids clearing gel from high concentrations of bleach and allows it to move toward regions of the tray where lower concentrations are present.[6] Last, some authors state the reservoir allows for improved tray seating when more viscous whitening materials are used.[7]

While the logic for the reservoir is seemingly reasonable, there is still a considerable amount of debate on the necessity of its presence. While several studies indicate a significant difference between trays with reservoirs and trays without reservoirs in tooth whitening efficacy,[8] the majority of studies show the opposite. Thus, there is no statistical evidence for the benefits of reservoir usage.[5,9-13]

While a more viscous whitening product has proven to be vital in the success of at-home tooth whitening, it is unclear whether the creation of reservoirs is indeed a beneficial step in the tray-fabrication process. Without the use of reservoirs in the whitening trays, the amount of whitening material used to lighten teeth could be reduced as well as time and material for tray fabrication.[10] Because, the effects of whitening occur from exposure area and time instead of volume, reservoirs allowing increased space for additional bleach beyond tooth coverage may or may not be a significant element in whitening trays. Moreover, it is not clear whether the presence of the tray's reservoir can actually be damaging to the oral cavity due to increased inflammation where reservoirs are present.[14] As the nation continues to seek an esthetic smile, it is essential that these uncertainties need to be solved in order to avoid unwarranted expenses and manufacturing time, as well as potential harm to the patient that may result from increased inflammation. Thus, it would behoove the dental community to continue to investigate and better understand the effects of tray reservoirs more thoroughly. Upon an enhanced knowledge based on the utilization of reservoirs, tray fabrication can be either adjusted or solidified after appreciating the full spectrum of the reservoir's purpose and impacts.

The aim of this study was to evaluate the efficacy and necessity of using reservoirs in tooth whitening tray fabrication with different formulations of whitening gels. We determined the efficacy of trays made with and without reservoirs by measuring color change of extracted teeth treated with two different formulations of at-home whitening materials. We hypothesized there would be no statistical significance in color change related to the presence or absence of reservoirs for both whitening formulations.

MATERIALS AND METHODS

Sample selection and mounting on typodonts: A total of sixty extracted human teeth without identifiers (central incisors n = 20; canines n = 20; molars n = 20) were used in the study. Additionally, sixty artificial teeth (lateral incisors n = 20; premolar n = 40) were used to facilitate mounting teeth in a dental typodont to form an arch. The Institutional Review Board at the University of Iowa approved the use of extracted teeth as a non-human subjects research (IRB # 201407710). The extracted teeth were stored in 0.2% sodium azide solution at 4°C. Teeth were cleaned of gross debris and placed in artificial saliva for 24 hours at 37°C prior to initiating the experiment. Teeth were mounted on ten maxillary typodonts (KaVo Dental, Charlotte, NC, USA) with the use of silicone impression material (Aquasil Ultra, Dentsply, York, PA, USA) alternating with artificial typodont teeth to create an upper arch. Each typodont consisted of two central incisors, two canines and two molars. The space filled in between the natural teeth was occupied with typodont teeth consisting of two lateral incisors, and the four remaining premolars. This arrangement is depicted in Figure 1.

Custom made tray fabrication: Alginate impressions of the mounted typodonts were poured with yellow stone (Whip Mix Corporation, Louisville, KY, USA). A thin layer of block-out resin (Ultradent Products Inc., South Jordan UT, USA) was applied on the teeth of the right or left side of the typodont so that the facial surface was covered with the exception of 1 mm mesially, distally, cervically and incisally. This allowed for a split arch design within the same whitening formulation used. The time required for placing block-out resin was recorded. The fabrication

Fig. 1: Typodont set-up with extracted human teeth and artificial typodont teeth

Fig. 2: Split arch application of block-out reservoirs

Fig. 3: Spectrophotometric tooth color measurement with a custom fabricated tray with apertures for repeated measurements

set-up is demonstrated in Figure 2. Upon completion of reservoirs the model was soaked in soap water for 10 minutes to facilitate removal of the tray. Soft vinyl sheets of 1 mm thickness (Biostar, Great Lakes Orthodontics Ltd., Tonawanda, NY, USA) was heated on a heat pressure machine (Ministar, Great Lakes Orthodontics Ltd., Tonawanda, NY, USA) and formed to fabricate a custom tray. The tray was separated from the model and scalloped along the gingival margins and stored in a tray case to avoid any deformation.

Whitening protocol by experimental group: Whitening with the custom fabricated trays was performed based on two different whitening regimens and tray types: OPAL-NR: use of Opalescence PF (Ultradent Product Inc, South Jordan, UT, USA) a 10% carbamide peroxide gel for 8 hours in a tray without reservoir; OPAL-WR: use of Opalescence PF in a tray with reservoir; DW-NR; use of Philips DayWhite (Philips Oral Health Care, LA, CA, USA) a 9.5% hydrogen peroxide gel for 30 minutes twice daily in a tray without reservoir; DW-WR: use of Philips Day White in a tray with reservoir. Both systems were applied for 7 consecutive days with the models being stored in artificial saliva at room temperature between the treatments.

Tooth color change assessment: A contact type intra oral spectrophotometer (VITA Easyshade® Advance 4.0, VITA Zahnfabrik, Bad Sackingen, Germany) was used for the color measurements on the middle third of the buccal surface with the use of a custom fabricated clear jig for repeatable measurements (Fig. 3). Measurements were performed under a color controlled lightening box (MM 4e GTI Mini Matcher, GTI Graphic Technology, Inc, Newburgh, NY, USA) at CIE D_{65}, a color temperature of 6500K and light intensity of ≈ 1200 lux. The overall color change as measured with the spectrophotometer was expressed as ΔE* from the Commission Internationale de I′ Eclairage.[15] The following equation was used:

$$\Delta E^* = [(L^*_2 - L^*_1)^2 + (a^*_2 - a^*_1)^2 + (b^*_2 - b^*_1)^2]^{1/2}$$

The color differences were calculated relative to baseline color parameters (L^*_1, a^*_1, b^*_1).

For each whitening regimen, five trays were used that had reservoirs on one side and no reservoirs on the other side. There were 12 teeth (natural teeth n = 6; artificial teeth n = 6) in each tray, where three natural teeth and three artificial teeth are with reservoirs and other six teeth without reservoirs. Color measurements were obtained at baseline (T_1), 1-day post-whitening (T_2), and 1-month post-whitening (T_3).

Statistical analysis: One-way ANOVA was conducted to assess the difference in the three color parameters (i.e. L*, a*, b*) among the four experimental groups at baseline. Descriptive statistics were computed for the overall color change. One-way ANOVA followed by the post hoc Tukey's HSD (Honestly Significant Difference) test, was used to detect the significant difference in the overall color change among the four techniques of tray fabrication at 1-day and 1-month post-whitening treatment.

Additionally, a paired-sample t-test was used to assess a significant difference in the overall color change between 1-day and 1-month post-whitening treatment within each of the four techniques of tray fabrication.

All tests utilized a 0.05 level of significance, and statistical analyses were performed using the statistical package SAS® System version 9.3 (SAS Institute Inc., Cary, NC, USA).

RESULTS

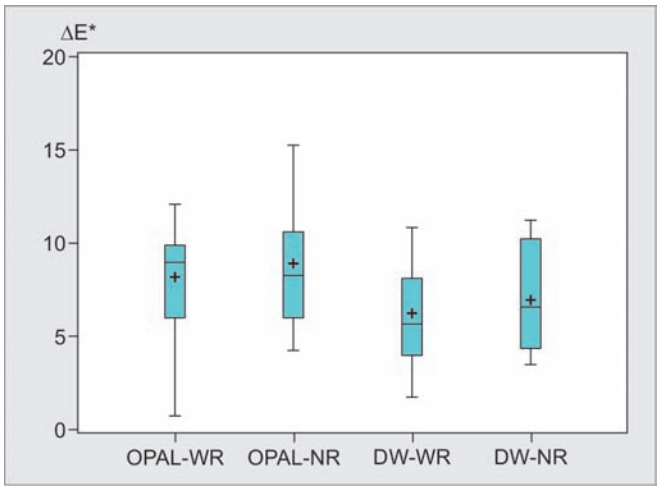
A total of 60 extracted sound human maxillary teeth were obtained, then were randomly equally divided into four groups by tray type and whitening material (n = 15/per group). The overall color changes (ΔE*) by group at each of the two time points after the whitening treatment

1-day post-whitening (T_2) and 1-month post-whitening (T_3) are summarized in Table 1 and illustrated as boxplots in Figure 3.

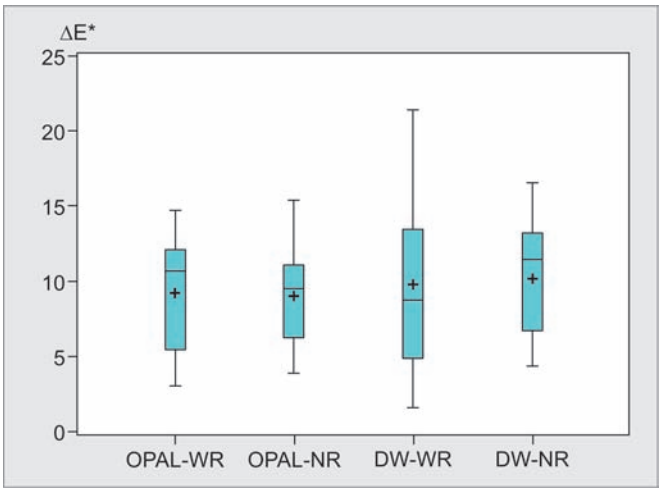
Results of one-way ANOVA revealed that there were no significant differences among the four groups at baseline with respect to L*, a*, and b* ($p > 0.05$ in all instances) and on the overall color change at 1-day post-whitening treatment ($p = 0.0789$) and at 1-month post-whitening treatment ($p = 0.8670$) that are also depicted in the boxplots (Graphs 1 and 2).

Based on the paired-sample t-test, there were no significant differences in the mean overall color change between 1-day and 1-month post-whitening treatment for OPAL-NR technique ($p = 0.9169$) and OPAL-WR ($p = 0.2535$).

However, the data provided evidence that there was a significant difference in the mean overall color change between 1-day and 1-month post-whitening treatment for DW-NR and DW-WR technique. It indicated that the mean overall color change observed at 1-month post-whitening was significantly greater than that for the 1-day post-whitening (10.19 *vs* 6.96, $p = 0.0026$ for DW-NR and 9.79 *vs* 6.23, $p = 0.0031$ for DW-WR; respectively).



Graph 1: Boxplots of overall color change (ΔE*) by group at 1-day post whitening



Graph 2: Boxplots of overall color change (ΔE*) by group at 1-month post-whitening

Table 1: Overall color change of the four experimental groups by time point (Mean/SD)

Groups	*1-day post-whitening (T_2)*	*1-month post-whitening (T_3)*
OPAL-WR	8.20/2.95^{aA}	9.14/3.55^{aA}
OPAL-NR	8.94/3.53^{aA}	9.02/3.32^{aA}
DW-WR	6.23/2.84^{aA}	9.79/5.88^{aB}
DW-NR	6.96/2.85^{aA}	10.19/4.12^{aB}

Within the columns, same lower case letters indicate no significant difference using the post hoc Tukey's HSD test ($p > 0.05$)
Within the rows, same upper case letters indicate no significant difference using the post hoc Tukey's HSD test ($p > 0.05$)

The recorded median time for a dental student to create reservoirs on half of the cast was 9.42 minutes.

DISCUSSION

Demand for tooth whitening has been growing over the past years and tooth whitening now represents the most common elective dental procedure.[16] More than 1 million Americans whiten their teeth annually, driving nearly $600 million in revenues for dental offices.[16] The vast variety of available whitening modalities: professionally applied in-office whitening; professionally dispensed patient-applied home whitening; over-the-counter (OTC) products and do-it-yourself whitening, reflect the high demand of consumers and patients.[17]

To keep pace with this trend and provide better whitening results, scientists have put great effort into developing new whitening technologies: the introduction and marketing of the over-the-counter whitening strips serve as a good example. Since their introduction in 2000,[18] manufacturers have improved the use of strips by changing the formulation, application regimen and delivery system, including the advanced adhesion technology to make it more user-friendly.[19] Contrasted to the continuous improvements of whitening strips, professionally dispensed patient-applied home whitening with the use of custom fabricated trays has not made any major innovations since their introduction in the scientific literature in 1989. Therefore, while incorporating a reservoir in a tray is not a difficult process, it still requires extra amount of auxiliary time chair-side. If this time and additional block-out material can be eliminated, it would make the process not only more efficient but may also prove to be safer due to less whitening material needed to fill the tray.

Our study evaluated the presence and absence of reservoirs related to overall tooth color change. Based on the results, our hypothesis was accepted. There was no significant difference in color change related to the

presence or absence of reservoirs regardless of the whitening formulations used. Therefore, while the rationale for using reservoirs as recommended by manufacturers appears sound. the study results did not support its use in whitening trays to improve tooth whitening efficacy. This is in accordance with many clinical studies that showed no significant difference in tooth color change related to the use of reservoirs.[5,9-12] Conceivably even more critical, an additional study showed an increase in gingival inflammation when trays with reservoirs were used in comparison to trays without reservoirs which was attributed to the fact that the decreased retention in the presence of reservoirs allowed more extrusion of the whitening material.[14]

However, it is noteworthy to mention a clinical study that demonstrated a greater bleaching effect on teeth when trays with reservoirs were used in comparison to trays without reservoirs,[8] and another study where a significant increased overall color change for trays with reservoirs was depicted with instrumental tooth color measurements.[10]

An interesting aspect of this study was the difference in formulations (carbamide peroxide *vs* hydrogen peroxide) and application time (30 min. twice *vs* 8 hrs.) at different time points. The overall tooth color change with 10% carbamide peroxide was stable over 1 month whereas whitening with 10% hydrogen peroxide induced a significantly higher color change at 1-month post-whitening compared to 1-day post-whitening, suggesting that incorporation of hydrogen peroxide was still active within the tooth for up to 1 month creating a lighter tooth color. This trend has also been noted in other *in vitro* studies when hydrogen peroxide based materials were used.[20] The results also suggest that for proper follow-up, color measurements should be performed beyond 1-day post-whitening.

The median time to prepare reservoirs on half of the arch was approximately 9.42 minutes for a dental student. According to the literature, it takes approximately 10 minutes per arch to fabricate reservoirs with block-out material,[5] that is expectedly much shorter than the time it took for a dental student.

As an *in vitro* study that used extracted teeth mounted in typodonts, it involves limitations of not fully replicating the dynamics of the oral cavity with the absence of saliva and the absence of positive outward pulpal pressure associated with vital teeth. Furthermore, the study could not address sensitivity or gingival irritation issues associated with at-home whitening. However, a clinical study by Matis et al have indicated that there was no significant difference of occurrence or severity of sensitivity between the two types of tray design.[10] Lastly, the study did not quantify the exact amount of whitening material used for the reservoir *vs* non-reservoir groups. Therefore, future studies on the minimal amount of whitening material needed without compromising whitening efficacy would be paramount to establish a more controlled and safer whitening procedure.

CONCLUSION

Within the limitations of this study, it can be concluded that the use of trays with or without reservoirs was equally effective in whitening teeth.

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