Jurnal Aisyah: Jurnal Ilmu Kesehatan

Volume 9, Issue 2, September 2024, p. 1383–1382
ISSN 2502-4825 (print), ISSN 2502-9495 (online)

The Effect of Immersion of Heat-Cured Acrylic Resin Denture Bases Exposed to Filter Cigarette Smoke in Sodium Bicarbonate and Apple Cider Vinegar Denture Cleanser on Discoloration

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ABSTRACT

Background: Cigarette smoke may cause discoloration of denture bases, thereby reducing their aesthetic quality. Therefore, an effective denture cleansing solution is needed. Commercial effervescent denture cleansers are commonly used; however, they are relatively expensive and not easily accessible for some communities. **Aim:** To evaluate the effect and effectiveness of sodium bicarbonate solution combined with apple cider vinegar at various concentrations in preventing discoloration of heat-cured acrylic resin denture bases exposed to cigarette smoke. **Methods:** This study used a laboratory experimental design with a post-test control group design. The samples were divided into five groups, consisting of two control groups and three treatment groups: sodium bicarbonate combined with 1 percent, 10 percent, and 20 percent apple cider vinegar. Each group was observed for 21 days. Color changes were measured daily, and the results were calculated using the Delta Eab formula and then averaged. **Results:** Significant differences were found between the negative control group and both the positive control group and the treatment groups. The findings indicated that the cleaning solution containing sodium bicarbonate and apple cider vinegar at concentrations of 1 percent, 10 percent, and 20 percent was effective in inhibiting discoloration of heat-cured acrylic resin denture bases exposed to cigarette smoke. **Conclusion:** Immersion of heat-cured acrylic resin denture bases exposed to filter cigarette smoke in a denture cleanser containing sodium bicarbonate and apple cider vinegar affected the inhibition of discoloration. The most effective concentration was 50 percent sodium bicarbonate combined with 20 percent apple cider vinegar.

Keywords: Apple cider vinegar, cigarette smoke, denture base.

ABSTRAK

Latar Belakang: Paparan asap rokok dapat memicu perubahan warna pada gigi tiruan, sehingga diperlukan larutan pembersih untuk mempertahankan aspek estetika protesa gigi tiruan. Saat ini, pembersih yang umum digunakan adalah larutan *effervescent* komersial. Permasalahannya, bahan ini memiliki harga yang relatif tinggi dan sulit dijangkau oleh berbagai lapisan masyarakat, sehingga diperlukan alternatif zat pembersih gigi tiruan. **Tujuan:** Untuk mengetahui dampak serta keefektifan berbagai konsentrasi larutan natrium bikarbonat yang dikombinasikan dengan cuka apel dalam mencegah terjadinya perubahan warna pada gigi tiruan berbahan resin akrilik *heat cured* yang telah terpapar asap rokok. **Metode:** Penelitian ini menggunakan rancangan eksperimental laboratorium dengan desain *post-test control group design*. Sampel terbagi menjadi 5 kategori, yaitu 2 kategori kontrol dan 3 kategori perlakuan (natrium bikarbonat + cuka apel 1%, natrium bikarbonat + cuka apel 10%, natrium bikarbonat + cuka apel 20%), dengan masing-masing perlakuan diulang selama 21 hari. Pengukuran warna pada sampel dilakukan setiap hari. **Hasil:** Terdapat pengaruh yang bermakna pada perbedaan antara Group kontrol negatif dengan Group kontrol positif maupun dengan Group perlakuan. Hasil penelitian menunjukkan bahwa larutan pembersih natrium bikarbonat dan cuka apel pada konsentrasi 1%, 10%, maupun 20% efektif dalam memperlambat perubahan warna pada basis gigi tiruan resin akrilik *heat cured* yang terpapar asap rokok. **Simpulan:** Perendaman basis gigi tiruan resin akrilik *heat cured* dengan paparan asap rokok filter ke dalam pembersih gigi tiruan natrium bikarbonat dan cuka apel memberikan pengaruh dalam menghambat perubahan warna, dan konsentrasi yang paling efektif adalah natrium bikarbonat 50% dengan cuka apel 20%.

Kata Kunci : Basis gigi tiruan, cuka apel, rokok filter.

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INTRODUCTION

Heat-cured acrylic resin remains one of the most widely used materials for denture bases because of its acceptable aesthetic quality, ease of fabrication, adequate mechanical properties, and relatively affordable cost. In prosthodontic treatment, this material is commonly used to support artificial teeth and restore oral function in partially or completely edentulous patients (Firouz et al., 2024; Gad et al., 2024; Garach, 2021). Despite these advantages, heat-cured acrylic resin still has several limitations, particularly its susceptibility to water sorption, surface porosity, and reduced color stability over time (Diwan et al., 2006; Nallaswamy et al., 2004). These limitations may affect not only the physical quality of the denture base but also its long-term aesthetic acceptability, especially when the material is repeatedly exposed to staining agents in the oral environment.

Color stability is an important clinical requirement for denture base materials because dentures are expected to maintain their appearance during long-term use. Discoloration of acrylic resin may occur due to intrinsic and extrinsic factors. Intrinsic discoloration is commonly associated with material composition, polymerization process, residual monomer, and internal chemical degradation of the resin matrix (Alfouzan et al., 2023; Makkeyah et al., 2024). Extrinsic discoloration is more closely related to oral hygiene habits, dietary patterns, and exposure to chromogenic substances. The porous structure and fluid-absorbing nature of acrylic resin can facilitate the penetration and retention of pigments, resulting in visible color changes on the denture surface (Imirzalioglu et al., 2010).

One of the common extrinsic factors contributing to denture discoloration is smoking. Cigarette smoke contains various chemical substances, including nicotine, tar, carbon monoxide, and other particulate compounds that may adhere to oral structures and dental prostheses (Alfouzan et al., 2021; Mugri et al., 2023; Tekin, 2021). Tar in particular has a brownish and sticky characteristic, making it capable of accumulating on the surface of acrylic resin and producing stains that are difficult to remove through ordinary rinsing. In denture wearers, prolonged exposure to cigarette smoke may gradually reduce the brightness and aesthetic quality of the denture base (Patil et al., 2013), this condition may affect patient satisfaction, self-confidence, and willingness to use dentures regularly.

The relevance of this issue is particularly strong in Indonesia, where smoking remains a common lifestyle habit. Indonesia has been reported as one of the countries with the highest smoking prevalence in Southeast Asia (Tan & Dorotheo, 2018). Filter cigarettes are also among the commonly consumed cigarette products in Indonesia, making exposure(Indonesia, 2013) to filter cigarette smoke a clinically relevant factor in studies related to denture discoloration. Previous dental studies have shown that smoking habits can contribute to discoloration of oral structures and dental materials, including acrylic-based artificial teeth and denture bases (Patil et al., 2013; Susanto et al., 2018). These conditions highlight the need for effective denture-cleaning strategies that can help reduce discoloration caused by cigarette smoke exposure.

Regular denture cleaning is essential to maintain oral hygiene, prevent microbial accumulation, preserve the physical quality of the denture base, and minimize aesthetic deterioration. Denture cleansers are commonly used as chemical cleaning agents because they can reach surface irregularities that may not be adequately cleaned by mechanical brushing alone (Gad et al., 2021; Takhtdar et al., 2023). Commercial effervescent denture cleansers are widely available and have been shown to assist in removing stains and deposits from denture surfaces. These products generally contain active ingredients that can release oxygen, break down organic debris, and support the removal of discoloring substances. Commercial denture cleansers may not be equally accessible to all denture users due to cost, availability, and socioeconomic differences. This condition creates a practical need for alternative denture cleansers that are affordable, easy to obtain, and potentially effective.

Sodium bicarbonate has been recognized as a material with potential benefits in oral hygiene care. It has mild abrasive properties, buffering capacity, and cleansing ability, making it useful in removing plaque and stains without causing excessive damage when used properly (Bhat et al., 2014; Novitasari et al., 2019; Takhtdar et al., 2023). Sodium bicarbonate-based denture cleansers have also been reported to be relatively safe for resin surfaces, suggesting their potential as an alternative cleaning material for acrylic-based dentures (Jayachandran & Madeswaran, 2018). Sodium bicarbonate has been associated with stain removal and whitening effects, particularly because of its ability to support the removal of extrinsic discoloration (Fotovat et al., 2024; Mirmortazavi et al., 2023), these characteristics make sodium bicarbonate a promising candidate for use as an alternative denture-cleaning agent, especially for acrylic resin materials exposed to staining substances.

Apple cider vinegar is another natural substance that may be useful as a cleaning agent because of its acetic acid content. Acetic acid has the potential to dissolve deposits and contribute to stain reduction through chemical interaction with organic and inorganic residues. Apple cider vinegar may also contain other compounds derived from the fermentation process that support its cleansing properties (Alqanas et al., 2022; Moharamzadeh, 2017; Valkenburg et al., 2019). Previous research has indicated that vinegar-based solutions may have potential in oral hygiene applications, particularly because of their antimicrobial and cleaning-related properties (Komiyama et al., 2010; Zidan et al., 2020). The acidic nature of apple cider vinegar may help weaken stain adhesion on acrylic resin surfaces, while its combination with sodium bicarbonate may produce a broader cleaning effect through the interaction of acidic and alkaline components.

Although sodium bicarbonate and vinegar-based solutions have been discussed in previous dental studies, evidence regarding their combined effect on the color stability of heat-cured acrylic resin denture bases remains limited (Kaneko et al., 2000; Naeem et al., 2015). Studies evaluating the ability of sodium bicarbonate combined with different concentrations of apple cider vinegar to inhibit discoloration caused by filter cigarette smoke are still scarce. This research gap is important because cigarette smoke exposure creates a specific type of extrinsic discoloration, mainly associated with tar and other smoke-related particles, which may behave differently from stains caused by beverages or food coloring.

Based on this background, the present study aimed to evaluate the effect of immersion in sodium bicarbonate and apple cider vinegar denture cleanser on the discoloration of heat-cured acrylic resin denture bases exposed to filter cigarette smoke. This study also aimed to compare the effectiveness of different apple cider vinegar concentrations combined with sodium bicarbonate in inhibiting color change. The findings are expected to provide preliminary laboratory evidence regarding the potential use of sodium bicarbonate and apple cider vinegar as an accessible alternative denture cleanser, particularly for denture wearers who are regularly exposed to cigarette smoke.

RESEARCH METHOD

This study used a laboratory experimental design with a post-test control group design. The research began with sample preparation, manufacturing of a smoking simulation device, artificial saliva preparation, and preparation of cleaning solutions. The research samples were heat-cured acrylic resin denture bases in the form of test plates measuring 10 mm x 10 mm with a thickness of 2 mm. The number of research samples was calculated using the Federer formula, yielding a minimum sample size of 5 plates. In this study, 1 reserve sample was used for each group, so the total number of samples used across 5 groups was 30 samples. The sample inclusion criteria were: heat-cured acrylic resin plates measuring 10 mm x 10 mm, 2 mm thick, and finely polished. The sample exclusion criteria were: heat-cured acrylic resin plates that were porous, cracked or broken, or contaminated with other substances (dirty samples). The samples in this study were produced by a laboratory under the brand Ivoclar.

The smoking simulation device was made using a closed container with holes drilled in the top surface to allow cigarette smoke to enter, and a hole at the bottom of the container to accommodate a 100 mL syringe that would represent suction. The cigarettes used in this study were Marlboro Filter Black brand filter cigarettes containing 1.9 mg of nicotine and 28 mg of tar. The artificial saliva in this study was prepared to resemble normal oral saliva and contained 0.1% albumin, 0.75% methylcellulose, 0.062% potassium chloride, 0.034% potassium phosphate, and 0.01% sodium fluoride, which were then dissolved in water and mixed with a second solution containing 0.2% methylparaben, 0.005% magnesium chloride, and 4.69% dextrose. A commercial cleaning solution under the brand Polydent 3 Minute Daily Cleanser was also prepared for use in the positive control group.

In this study, there were 5 groups: 1 negative control group (Group I), 1 positive control group (Group II), and 3 treatment groups (sodium bicarbonate + 1% apple cider vinegar (Group III), sodium bicarbonate + 10% apple cider vinegar (Group IV), sodium bicarbonate + 20% apple cider vinegar (Group V)). Group I was the negative control group; after smoking exposure, the samples were rinsed with distilled water and then immersed in artificial saliva solution, repeated for 21 consecutive days. Group II was the positive control group; after the smoking procedure, the samples were rinsed with distilled water and then immersed in Polydent 3 Minute Daily Cleanser commercial cleanser for 3 minutes, repeated for 21 consecutive days. Groups III, IV, and V were the treatment groups; after undergoing the smoking process, the samples were rinsed with distilled water and each treatment group was immersed in a sodium bicarbonate + apple cider vinegar solution at predetermined concentrations for 30 minutes, repeated for 21 consecutive days.

After being immersed in the cleaning solution, the samples were then rinsed with distilled water and data were collected in the form of photographs. Photographs of the samples were also taken before the start of the study. Photographs of the base plates were taken using a Sony Nex 7 camera with a 40-watt light source and were performed daily after treatment. After data were collected each day, the samples were immersed in artificial saliva solution and stored to be treated again the next day for 21 consecutive days. The photographs were then entered into Adobe Photoshop CC software to obtain L*a*b* color space data from the sample photographs. There is a delta value in the CIELab color scale. This study measured color change or ΔE*ab, specifically after one week, two weeks, and three weeks. The delta formula is as follows[11]:

$$\Delta E^*_{ab} = \sqrt{(L^*_2 - L^*_1)^2 + (a^*_2 - a^*_1)^2 + (b^*_2 - b^*_1)^2}$$

The values L_1, a_1, b_1* represent the data measured from heat-cured acrylic resin specimens before exposure to cigarette smoke or those that had been exposed in the previous week. Meanwhile, the values L_2, a_2, b_2* represent data obtained from the same specimens in the following week or from other groups. The resulting ΔEab value indicates the comparison of the degree of discoloration in heat-cured acrylic resin specimens, whether those that received treatment or those in the

control groups, from one week to the next. Subsequently, these ΔEab values were compared between groups against the control group.

RESULTS OF STUDY

Data obtained from color measurements using L, *a*, b* parameters for each specimen were analyzed to determine the magnitude of color change expressed as Δ*Eab value. The calculation results were then averaged and presented in tabular form. In summary, the average ΔE*ab values for each group during the first, second, and third week observation periods can be seen in Table 1.

Table 1. Repeated Anova Test

Group	n (%)	Color Change Value (ΔE^*_{ab})			*p-value*
		Week1	Week2	Week3	
		Mean ± SD	Mean ± SD	Mean ± SD	
Group I	6	46,44 ± 1,37	24,45 ±1,44	7,59 ± 1,57	0,00*
Group 2	6	27,88 ± 1,71	13,19 ± 0,94	4,50 ± 1,26	0,00*
Group 3	6	37,02 ± 1,48	15,40 ± 1,89	5,38 ± 1,21	0,00*
Group 4	6	35,70 ± 1,39	12,98 ± 0,52	4,72 ± 0,55	0,00*
Group 5	6	32,96 ± 1,93	11,73 ± 0,65	3,87 ± 0,74	0,00*

**normality test, shapiro-wilk test: p>0,05; data distribution normal*
**Repeated Anova test: p<0,05 ; significant*

Source: data proceed

Based on Table 1, it can be seen that the ΔEab values for each group show a fluctuating trend. Group I as the negative control had the highest ΔEab value, while Group V as the treatment group with a concentration of 50% sodium bicarbonate and 20% apple cider vinegar showed a relatively low ΔE*ab value. The results of the Shapiro-Wilk normality test in Table 2 indicate that all data were normally distributed with a significance value greater than 0.05.

Table 2. Paired Sample T-test Week 1 – Week 3

Group	Week1 – Week3	
	Mean difference	Sig.
Group I	38,84333	0.000*
Group II	23,37833	0,000*
Group III	31,63833	0,000*
Group IV	30,98500	0,000*
Group V	29,09167	0,000*

Source: data proceed

In the Paired T-Test, the results showed that color change between the first and third weeks yielded significant results for all five groups (p<0.05). The highest comparison value between the first and third weeks was found in Group I (negative control), while the lowest comparison value was found in Group II (positive control). Nevertheless, among the three treatment groups, the lowest comparison value was found in Group V (50% sodium bicarbonate + 20% apple cider vinegar). This indicates that Group V experienced the least color change compared to the other treatment groups (Group III; 50% sodium bicarbonate + 1% apple cider vinegar and Group IV; 50% sodium bicarbonate + 10% apple cider vinegar). The mean difference of ΔE*ab in Group II was lower compared to Group V. It can be said that Group II provided better results in preventing color change.

After assessing within-group changes over time, a one-way ANOVA test was conducted to compare the mean ΔE*ab values among the five groups at each observation period. This analysis aimed to determine whether the type of immersion solution produced significant differences in discoloration inhibition during the first, second, and third weeks. The descriptive values and statistical comparison of color changes among groups are presented in Table 3.

Table 3. One-way Anova Test

Group	n (%)	Color Change Value (ΔE^*_{ab})		
		Week1	Week2	Week3
		Mean ± SD	Mean ± SD	Mean ± SD
Group I	6	46,44 ± 1,37	24,45 ±1,44	7,59 ± 1,57
Group II	6	27,88 ± 1,71	13,19 ± 0,94	4,50 ± 1,26
Group III	6	37,02 ± 1,48	15,40 ± 1,89	5,38 ± 1,21
Group IV	6	35,70 ± 1,39	12,98 ± 0,52	4,72 ± 0,55

Group V	6	32,96 ± 1,93	11,73 ± 0,65	3,87 ± 0,74
p-value		0,000*	0,000*	0,000*

**Normality test, Shaphiro-Wilk test p>0,05; data distribution normal*
**One-way Anova test: p<0,05; significant*

Source: data proceed

Table 3 presents the differences in mean color change values (ΔE*ab) among Groups I, II, III, IV, and V based on observation time. The statistical test results showed a p-value <0.05 for each week, thus it can be stated that the differences in ΔE*ab values among the five groups were statistically significant throughout the observation period. The analysis results also show that each week, Group I had the highest ΔE*ab value compared to other groups. Meanwhile, among the three treatment groups, Group V consistently showed the lowest ΔE*ab value each week.

To identify the significance of comparisons between groups each week, a post hoc Bonferroni test was conducted. In the first week, almost all comparisons between groups showed significant results, except for the comparison between Group III and IV and between Group IV and V. The largest difference was found in the comparison between Group I and II.

Table 4. Post-Hoc Bonferroni Test Week 1

	K1	K2	K3	K4	K5
K1		,000*	,000*	,000*	,000*
K2			,000*	,000*	,000*
K3				1,000	,002*
K4					,063
K5					

In the second week, statistically significant differences were observed between Group I and all other groups. No significant differences were found in the comparisons between Group II and Group IV, Group II and Group V, as well as Group IV and Group V. The largest difference in the second week occurred in the comparison between Group I and Group V. The post-hoc Bonferroni test in the first week showed significant differences between the negative control group and all other groups. This indicates that even in the early observation period, immersion in either commercial cleanser or sodium bicarbonate–apple cider vinegar solution had a measurable effect in reducing discoloration compared with no cleanser treatment. However, the comparison between Group III and Group IV was not statistically significant, suggesting that the difference between 1% and 10% apple cider vinegar concentrations was not yet strong enough to produce a clear statistical distinction during the first week. Similarly, the comparison between Group IV and Group V was not significant, indicating that the early effect of 10% and 20% apple cider vinegar concentrations was relatively comparable.

Table 5. Post-Hoc Bonferroni Test Week 2

	K1	K2	K3	K4	K5
K1		,000*	,000*	,000*	,000*
K2			,039*	1,000	,453
K3				,018*	,000
K4					,832
K5					

Source: data proceed

In the second week, the post-hoc analysis showed that Group I remained significantly different from all other groups, confirming that specimens without cleanser treatment continued to experience greater discoloration. Significant differences were also observed between Group II and Group III, as well as between Group III and Groups IV and V. These results indicate that the treatment solution with 1% apple cider vinegar had a weaker discoloration-inhibiting effect than the higher-concentration treatment groups. The absence of significant differences between Group II and Groups IV and V suggests that the 10% and 20% apple cider vinegar combinations began to show an effect approaching that of the commercial cleanser during the second week.

Table 6. Uji *Post-Hoc Bonfferoni* Week3

	K1	K2	K3	K4	K5
K1		,001*	,023*	,002*	,000*
K2			1,000	1,000	1,000
K3				1,000	,291
K4					1,000
K5					

Source: data proceed

Entering the third week, statistically significant differences were only detected between Group I and other groups, there were no statistically significant differences between Group II and III, Group II and IV, nor Group II and V. Comparisons between Group III and IV as well as Group III and V also did not show statistically significant differences. The comparison between Group IV and V was also not statistically significant, with a difference value of 0.84333. The largest difference in the third week was found in the comparison between Group I and V.

The third-week post-hoc Bonferroni test showed that significant differences were primarily found between Group I and the other groups. This pattern indicates that all cleanser-treated groups were able to inhibit discoloration more effectively than the negative control group after prolonged exposure to filter cigarette smoke. However, no statistically significant differences were observed among Group II, Group III, Group IV, and Group V in the third week. Although Group V showed the lowest mean ΔE*ab value among the sodium bicarbonate and apple cider vinegar treatment groups, the difference between Group V and the positive control group was not statistically significant. These findings suggest that the combination of 50% sodium bicarbonate and 20% apple cider vinegar may serve as the most effective alternative cleanser among the tested treatment solutions, while the commercial cleanser remained a strong reference standard for discoloration inhibition.

DISCUSSION

The etiology of extrinsic discoloration varies significantly among adults and is often influenced by oral hygiene habits and lifestyle, one of which is smoking[9]. Cigarettes contain various chemical substances released into the air in the form of particles, one of which is tar that can leave stains on teeth and dentures. In condensed form, tar is a brown, sticky consistency[10]. Aesthetics is one of the main functions of dentures, so it is important to maintain the color stability of dentures for patient satisfaction with their appearance. In this study, cleaning of heat-cured acrylic resin plates was carried out chemically to specifically examine the ability of the solution to inhibit color changes in dentures exposed to cigarette smoke by observing the magnitude of the difference in L*a*b* data (ΔE*ab). This aimed to observe the magnitude of changes that occurred from week to week in each group.

Based on the results of the study, it was observed that the ability of the sodium bicarbonate cleaning solution combined with apple cider vinegar to inhibit color change increased along with the increase in solution concentration. The analysis of ΔE*ab values showed statistically significant differences across all groups at each week of observation. The highest ΔE*ab value was recorded in Group I. This is because Group I was the negative control that did not receive any cleaning treatment. This finding indicates that hot filter cigarette smoke containing solid particles (tar) and chemical compounds (carbon monoxide and nicotine) can adhere to the surface of the denture base and cause substantial color changes (Fotovat et al., 2024; Mirmortazavi et al., 2023). The analysis results also revealed significant differences in Group II (positive control), Group III (50% sodium bicarbonate + 1% apple cider vinegar), Group IV (50% sodium bicarbonate + 10% apple cider vinegar), and Group V (50% sodium bicarbonate + 20% apple cider vinegar) each week. Therefore, to determine which group showed the most significant differences, a further Paired T-Test was conducted on each treatment.

The Paired T-Test results showed that the largest difference in color change values between the first and third weeks was found in Group I (negative control), while the smallest difference was found in Group II (positive control). Thus, immersion in commercial cleaning solution was proven to be the most effective in inhibiting discoloration. This advantage is most likely due to the active ingredients contained in the commercial cleanser Polydent 3 minute daily cleanser, namely sodium bicarbonate, citric acid, and sodium carbonate peroxide(Aritonang & Sinulingga, 2019). Citric acid is known to have the ability to whiten discolored teeth because its OH groups have the potential to act as an oxidizer in dissolving stains[15]. Sodium carbonate peroxide plays a role in triggering the formation of free radicals through an alkaline pH that is electrophilic and unstable, resulting in an oxidation-reduction reaction that converts dark-colored organic molecules into simpler and brighter molecules(Ural et al., 2011).

Among the three treatment groups, Group V (50% sodium bicarbonate + 20% apple cider vinegar) showed the smallest color change difference from the first to the third week. This finding is consistent with the statements of (Komiyama et al., 2010), that apple cider vinegar contains acetic acid as an active ingredient that undergoes oxidation, making it effective for decalcifying calculus deposits on the surface of heat-cured acrylic resin denture bases. The higher the concentration of apple cider vinegar used, the greater the ability of the solution to prevent color change. This is because oxidized acetic acid can break down dark-colored molecular chains into shorter and more soluble chains[11]. Thus, although not as effective as commercial cleansers, the combination of 50% sodium bicarbonate and 20% apple cider vinegar can serve as a more affordable alternative denture cleanser that remains effective in inhibiting discoloration due to exposure to filter cigarette smoke (Kafin & Saleh, 2018; Mustakim, 2016).

The Paired T-Test showed the difference in values between the first and third weeks. The largest difference was in Group I (negative control) and the smallest in Group II (positive control). Group II experienced the least change among all groups, so it can be concluded that immersion in commercial cleaning solution was the best at inhibiting color change. This may be because the commercial cleanser Polydent 3 minute daily cleanser contains sodium bicarbonate, citric acid, and sodium carbonate peroxide(Li, 2017). Citric acid has the ability to whiten discolored teeth because it has OH groups that have the potential to become oxidizers in dissolving stains. Sodium carbonate peroxide promotes the formation of

free radicals through an alkaline pH that is electrophilic and unstable, resulting in an oxidation-reduction process that turns dark-colored organic molecules into simpler and brighter molecules.

T(Li, 2017)he smallest difference value from the first to the third week among the three treatment groups was found in Group V (50% sodium bicarbonate + 20% apple cider vinegar). This is supported by the statement of Komiyama, et al. in 2010 and Naeem, et al. in 2015, that apple cider vinegar contains the active ingredient acetic acid which undergoes oxidation, making it effective for decalcifying calculus deposits on the surface of heat-cured acrylic resin denture bases(Jayachandran & Madeswaran, 2018; Li, 2017).

A One Way Anova test was conducted to observe the significance of changes in each group each week, and a Post-hoc Bonferroni test to observe the significance of comparisons between groups. In the One Way Anova test, the change values in each group were statistically significant each week. The Post-Hoc Bonferroni test showed that the comparison between Group I and III (50% sodium bicarbonate + 1% apple cider vinegar) in the first, second, and third weeks had the smallest value compared to other groups, thus it was concluded that Group III had the lowest effect in preventing color change. Although it only contained a 1% apple cider vinegar solution, the 50% sodium bicarbonate content could inhibit color change compared to groups not immersed in cleaning solution because it was still statistically significant. This may be because sodium bicarbonate oxidizes with oxygen, allowing it to dissolve debris and mucus, and is compatible with acidic solutions to maximize its mechanism (Aritonang & Sinulingga, 2019; Li, 2017; Moharamzadeh, 2017; Valkenburg et al., 2019). Sodium bicarbonate is also an abrasive material that is safe for use on dentures due to its low abrasivity(Li, 2017).

In the third week, the difference between Group II and V showed a positive value indicating that Group V was better at preventing color change, but it was not statistically significant. Comparisons between Group III and IV and between Group III and V showed significant results, but the comparison between Group IV and V did not show significant results. This indicates that Groups IV and V provided better results compared to Group III. The magnitude of the difference in the comparison between Group III and V shows that Group V was the best treatment group in preventing color change. The increase in apple cider vinegar concentration was directly proportional to its ability to prevent color change.

Apple cider vinegar obtained from the fermentation process contains acetic acid with a minimum concentration of 4%. The ability of apple cider vinegar to prevent color change cannot be separated from one of its active ingredients, namely acetic aci(Alhotan et al., 2022; Ferro et al., 2023). Oxidized acetic acid can then break down darker-colored molecular chains into simpler and more soluble chains(Alqutaibi et al., 2023; Al-Thobity et al., 2019; Amaya Arbeláez et al., 2020).

The above explanation shows that there was a significant difference between the negative control group and the treatment groups, so the results of this study indicate that all three solutions can inhibit color change in heat-cured acrylic resin denture bases exposed to cigarette smoke. The magnitude of the comparison values shows that Group V (50% sodium bicarbonate + 20% apple cider vinegar) had the best ability to inhibit color change compared to the other treatment groups. Group V had the highest concentration of apple cider vinegar, thus it could prevent color change better than other groups. Further research needs to be conducted on the effect of a cleaning solution of 50% sodium bicarbonate and 20% apple cider vinegar on the surface roughness of heat-cured acrylic resin denture bases to provide even better results.

CONCLUSION

Based on the results of the experimental study that has been conducted, it can be concluded that the immersion process of heat-cured acrylic resin denture bases exposed to filter cigarette smoke into a denture cleaning solution consisting of sodium bicarbonate combined with apple cider vinegar has a significant effect in slowing the occurrence of color change. Among the various concentrations tested, the cleaning solution with a composition of 50% sodium bicarbonate and 20% apple cider vinegar proved to be the most effective concentration in inhibiting discoloration of heat-cured acrylic resin denture bases due to cigarette smoke exposure.

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