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SHADE STABILITY OF MONOLITHIC ZIRCONIA CROWN IN TOBACCO USER : A COMPARATIVE IN VIVO STUDY

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ABSTRACT:
The aim of this study was to assess and compare the color stability of monolithic zirconia restorations among four groups of patients: non-tobacco users, smokers, smokeless tobacco users, and dual tobacco users (both smoking and smokeless tobacco). Color stability was evaluated at three time points: baseline, 6 months, and 12 months following restoration placement.

Material and Methodology: This prospective in vivo study was conducted in the Department of Prosthodontics at Hitkarini Dental College and Hospital and included 80 patients requiring monolithic zirconia crown and fixed partial denture restorations. The participants were randomly allocated into four equal groups based on their tobacco usage status: non-tobacco users, smokers, smokeless tobacco users, and dual tobacco users (individuals using both smoked and smokeless forms of tobacco).

All participants underwent a standardized clinical protocol, including tooth preparation, fabrication of provisional restorations, CAD/CAM milling of monolithic zirconia restorations, and definitive cementation. Color assessment was performed using the VITA Easyshade® V spectrophotometer under standardized operating conditions to ensure consistency. Baseline shade measurements were obtained immediately after final cementation, and subsequent evaluations were carried out at 6-months and 12-months follow-up visits. Color changes were analyzed according to the CIELAB color system. Statistical analysis was performed using SPSS software version 23.0, with a significance level set at $P < 0.05$.

Results: At the 6 months follow-up, no significant differences in the color stability of monolithic zirconia restorations were detected among the four groups ($P > 0.05$). In contrast, evaluation at 12 months revealed a statistically significant increase in discoloration among participants with tobacco habits compared with non-tobacco users ($P < 0.05$). Restorations in the non-tobacco group maintained complete color stability throughout the study period. Conversely, color changes were observed in 70% of smokers, 75% of smokeless tobacco users, and 90% of dual tobacco users. The greatest degree of discoloration was recorded in the dual-user group, suggesting that chronic exposure to both smoked and smokeless tobacco has a pronounced negative effect on the long-term esthetic performance and color stability of monolithic zirconia restorations.

Conclusion: Monolithic zirconia restorations exhibited excellent color stability during the initial 6-month period. However, extended exposure to tobacco was associated with a significant reduction in long-term shade stability. Non-tobacco users preserved the original esthetic appearance of their restorations throughout the study, whereas smokers, smokeless tobacco users, and individuals using both forms of tobacco experienced progressively greater discoloration over the 12-months follow-up. The most pronounced shade alteration was observed among dual tobacco users. These findings indicate that the cumulative duration and extent of tobacco exposure play a more influential role in color deterioration than the type of tobacco consumed, emphasizing the detrimental effect of chronic tobacco use on the long-term esthetic performance of monolithic zirconia restorations.

Clinical Significance: Monolithic zirconia restorations demonstrate excellent esthetic stability immediately after placement; however, long-term tobacco use can adversely influence their color stability and overall esthetic appearance. Consequently, a patient's tobacco-use history should be incorporated into the treatment planning process. Clinicians should also educate patients regarding the increased risk of restoration discoloration associated with continued tobacco consumption and emphasize the importance of regular maintenance visits and tobacco cessation to enhance the longevity and esthetic success of monolithic zirconia restorations.

KEYWORDS: Monolithic Zirconia Restorations, Tobacco Exposure, CIELAB Color System

INTRODUCTION

The demand for esthetic dental rehabilitation has increased considerably in modern prosthodontics, reflecting a greater focus on patient satisfaction, appearance, and overall quality of life. In fixed prosthodontics, the longevity of treatment is determined not only by the mechanical performance of the restoration but also by its ability to preserve an acceptable

esthetic appearance over time.[1] The development of all-ceramic restorative materials has enabled clinicians to fabricate restorations that closely resemble the color and translucency of natural teeth. Among the available ceramic systems, zirconia has become one of the most widely used materials because of its superior mechanical strength, excellent biocompatibility, and desirable esthetic properties.[2,3]

Yttria-stabilized tetragonal zirconia polycrystal (Y-TZP) is characterized by exceptional flexural strength and fracture toughness, making it a preferred material for restorations subjected to high occlusal loads, particularly in posterior regions.[2] The introduction of monolithic zirconia represented a significant advancement by eliminating the veneering porcelain layer, thereby minimizing the risk of porcelain chipping that has frequently been reported with bilayered zirconia restorations.[4,5] Furthermore, refinements in zirconia manufacturing, including increased translucency, optimized grain size, modified yttria content, and improved coloring protocols, have substantially enhanced the esthetic quality of monolithic zirconia restorations.[6]

An important determinant of the long-term success of esthetic restorations is their ability to maintain color over time. Shade stability describes the resistance of a restorative material to discoloration despite continuous exposure to the oral environment.[7] Numerous intrinsic and extrinsic factors, including saliva, thermal fluctuations, dietary pigments, oral hygiene practices, and restoration surface characteristics, can influence the color stability of dental materials.[8,9] Among these variables, tobacco use is recognized as a major extrinsic cause of staining affecting both natural dentition and restorative materials.[9,10]

Tobacco consumption remains highly prevalent in India, where individuals commonly use smoked forms such as cigarettes and bidis, as well as smokeless products including gutkha, khaini, and pan masala.[11] These products contain nicotine, tar, and various chromogenic compounds capable of depositing pigments on restorative surfaces, thereby altering their optical characteristics with prolonged exposure.[12,13] Although ceramic restorations generally demonstrate greater resistance to discoloration than resin-based materials, the shade stability of zirconia may still be affected by factors such as surface glazing, polishing techniques, surface roughness, and the surrounding oral environment.[14,15]

Previous in vitro studies have investigated the color stability of zirconia following immersion in staining agents such as coffee, tea, red wine, and nicotine-containing solutions.[16–18] While these laboratory investigations provide valuable preliminary evidence, they are unable to accurately replicate the complex conditions of the oral cavity, including salivary activity, individual oral hygiene practices, and prolonged exposure to tobacco products. Consequently, clinical evidence regarding the long-term color stability of monolithic zirconia restorations in tobacco users remains limited. For objective and reproducible color evaluation, digital shade-matching devices such as the VITA Easyshade® V spectrophotometer have become widely accepted, utilizing the CIELAB color system for standardized shade assessment.[20,21]

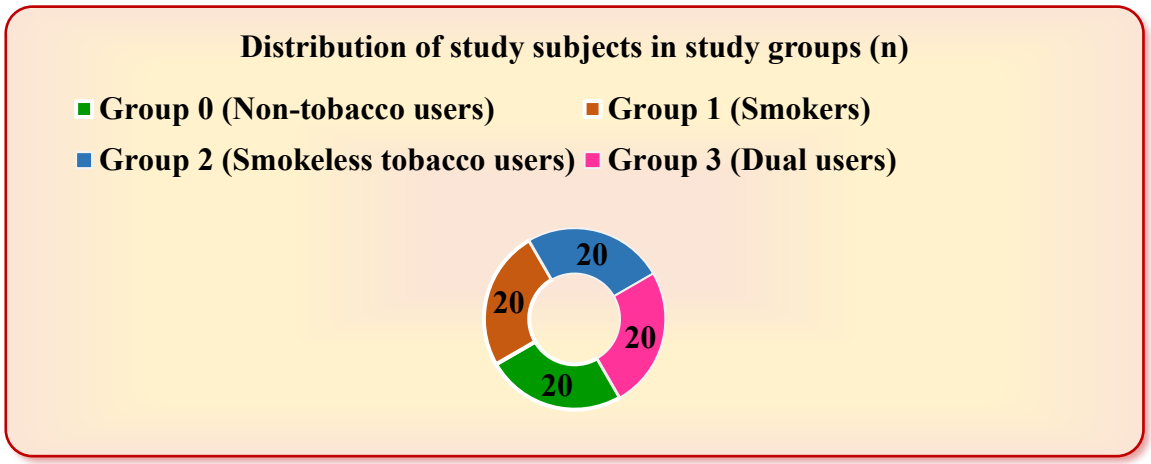
Therefore, the present in vivo study was designed to assess and compare the color stability of monolithic zirconia crowns among non-tobacco users, smokers, smokeless tobacco users, and dual tobacco users over a follow-up period of 12 months.

MATERIALS AND METHODS

This comparative in vivo clinical investigation was carried out in the Department of Prosthodontics, Hitkarini Dental College and Hospital, Jabalpur, Madhya Pradesh, India, between April 2024 and July 2025. Ethical clearance for the study was obtained from the Institutional Ethics Committee (Approval No. HDC&H/2024/1637/C). Prior to enrollment, all participants received a detailed explanation of the study protocol and provided written informed consent.

A total of 80 partially edentulous patients requiring fixed prosthodontic rehabilitation with monolithic zirconia crowns or fixed partial dentures were recruited for the study. The participants were equally allocated into four groups, with 20 subjects in each group (Graph 1):

Group 0: Non-tobacco users
Group 1: Smokers
Group 2: Smokeless tobacco users
Group 3: Dual tobacco users (both smokers and smokeless tobacco users)



Graph 1: Distribution of participants among the study groups.

The required sample size was calculated using G*Power software (Version 3.1.9.7) based on data obtained from a pilot study. A confidence level of 95% and a statistical power of 80% were considered for the sample size estimation.

Inclusion Criteria

- Individuals between 20 and 60 years of age.
- Partially edentulous patients requiring fixed prosthodontic rehabilitation.
- Non-tobacco users.
- Individuals with a history of smoking.
- Users of smokeless tobacco products.
- Dual tobacco users (smoking as well as smokeless tobacco).

Exclusion Criteria

- Patients diagnosed with systemic disorders such as gastroesophageal reflux disease (GERD).
- Individuals presenting with active oral infections, including oral candidiasis.
- Patients unwilling to adhere to the study protocol or attend scheduled follow-up appointments.

Preliminary diagnostic impressions were made using irreversible hydrocolloid impression material, and the resulting casts were poured in dental stone for diagnostic evaluation and treatment planning. Tooth preparation for monolithic zirconia restorations was performed according to standardized prosthodontic principles, incorporating an occlusal reduction of 1.0–1.5 mm, an axial reduction of 0.8–1.0 mm, and a deep chamfer finish line. All internal line angles were smoothly rounded to minimize stress concentration within the restoration. Gingival displacement procedures were completed before making the definitive impression to ensure precise recording of the finish line.

Shade selection was performed under standardized lighting conditions using both the VITA Classical Shade Guide and the VITA Easyshade® V spectrophotometer. To eliminate inter-examiner variability, all shade assessments were carried out by a single calibrated operator.

Provisional restorations were fabricated with bis-acrylic resin material and luted using a non-eugenol temporary cement. Definitive restorations were manufactured from yttria-stabilized tetragonal zirconia polycrystal (Y-TZP) blocks using CAD/CAM technology. Following milling, the restorations underwent sintering, characterization, glazing, and polishing before being clinically evaluated for marginal fit and occlusal accuracy.

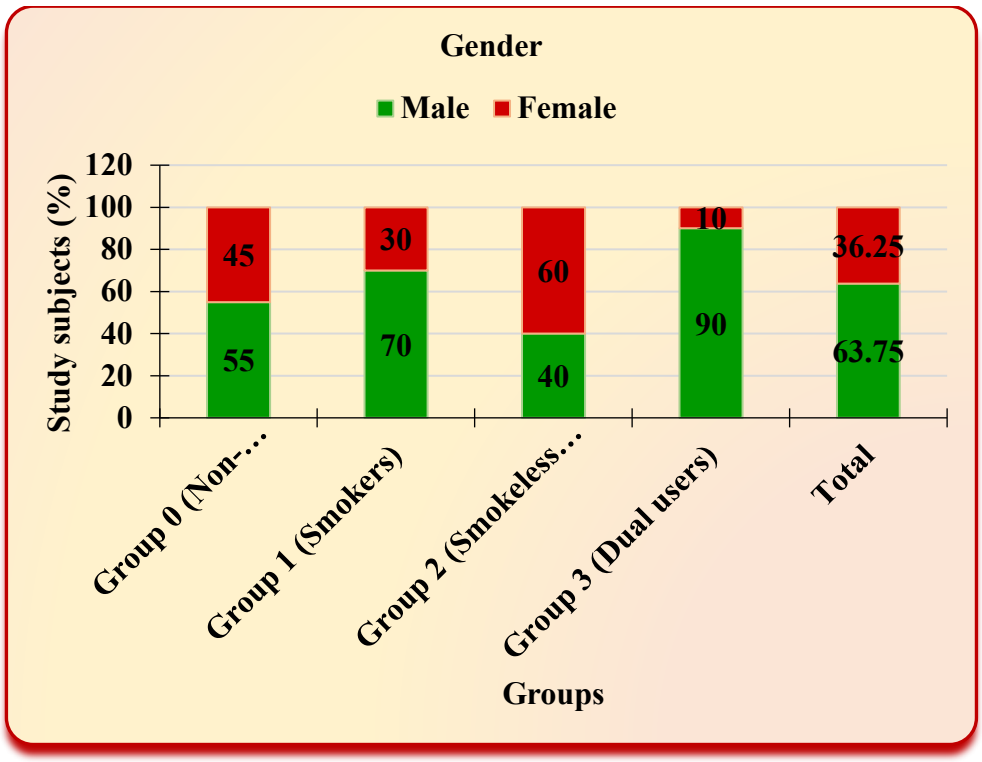
Before definitive cementation, the intaglio surfaces of the zirconia restorations were air-abraded using 50-µm aluminum oxide particles and conditioned with an MDP-containing zirconia primer to enhance bonding. Depending on the clinical situation, either self-adhesive resin cement or resin-modified glass ionomer cement was selected for final luting.

Color measurements were obtained immediately after cementation (baseline) and repeated at 6-month and 12-month follow-up visits using the VITA Easyshade® V spectrophotometer. The instrument was calibrated before each measurement session in accordance with the manufacturer's recommendations. Shade recordings were consistently made from the middle third of the buccal surface of each restoration under standardized environmental conditions. Three consecutive measurements were recorded for every restoration, and the average value was used for statistical evaluation.

Statistical analysis was performed using SPSS software version 23.0 (IBM Corporation, Armonk, NY, USA). Descriptive statistical methods were used to calculate means, standard deviations, frequencies, and percentages. Differences in age among the study groups were analyzed using one-way analysis of variance (ANOVA), while gender distribution was assessed using the Chi-square test. Changes in shade stability within each group over the study period were evaluated using Cochran's Q test, followed by the Mc Nemar test with Bonferroni correction for pair wise comparisons. Comparisons between groups were performed using the Chi-square test with Yates' correction whenever appropriate. Statistical significance was established at a *P* value of less than 0.05.

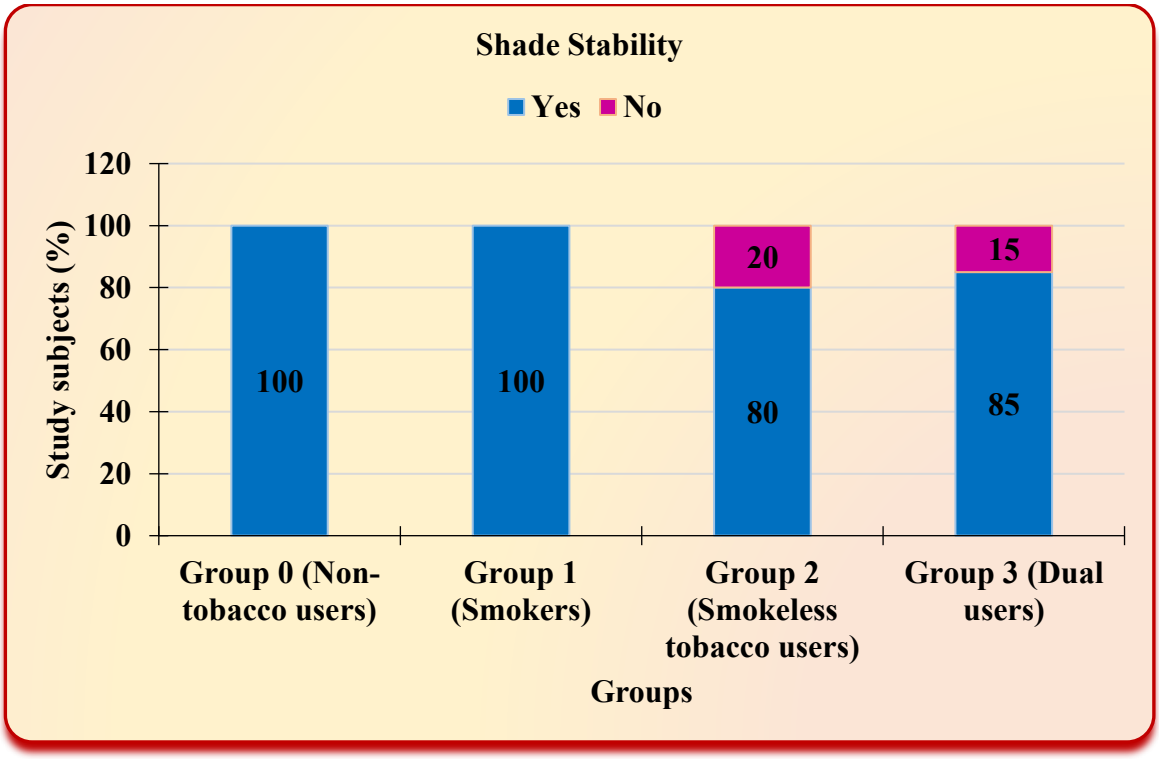
RESULTS

The study comprised 80 participants, who were evenly allocated into four groups: non-tobacco users, smokers, smokeless tobacco users, and dual tobacco users. The mean age of the participants varied from 37.00 ± 14.51 years in the non-tobacco group to 45.05 ± 11.23 years in the dual-user group. Statistical analysis revealed that the age distribution was comparable across all four groups, with no significant difference observed ($F = 2.013$, $P = 0.119$). In contrast, the distribution of gender showed a statistically significant difference among the study groups ($\chi^2 = 11.846$, $P = 0.008$). A higher proportion of male participants was noted in the smoker and dual-user groups compared with the other groups (Graph 2).

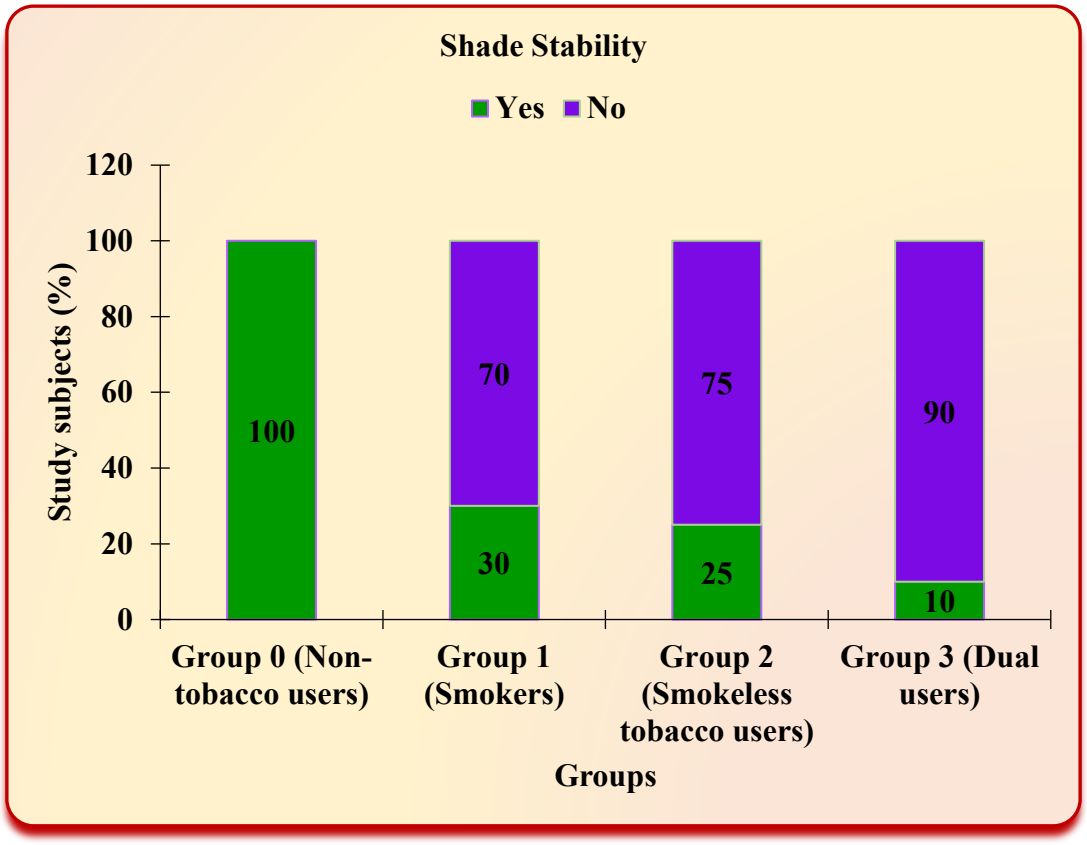


Graph 2: Comparison of gender distribution among the study groups.

Throughout the 12-months follow-up period, participants in the non-tobacco group maintained complete color stability, with no changes observed in their VITA shade scores. In the smoker group, shade values remained stable during the first 6 months; however, by the 12-month evaluation, 70% of the participants demonstrated a shift toward darker VITA shades, reflecting progressive discoloration. Among smokeless tobacco users, shade alterations were detected in 20% of participants at the 6-month follow-up, increasing markedly to 75% after 12 months. The greatest degree of color change was recorded in the dual tobacco user group, where 15% of participants exhibited discoloration at 6 months, rising to 90% at the end of the 12-month observation period. These findings indicate a progressive increase in discoloration with continued tobacco exposure, with the most pronounced changes occurring among dual users (Graphs 3 and 4; Tables 1–4).



Graph 3: Inter-group comparison of the color stability of monolithic zirconia crowns between baseline and the 6-months follow-up period.



Graph 4: Comparison of the color stability of monolithic zirconia crowns among the study groups from baseline to the 12-months follow-up period.

Patient no.	Baseline (T0)	After 6 months (T1)	After 12 months (T2)
1	A3.5	A3.5	A3.5
2	A3	A3	A3
3	C4	C4	C4
4	A4	A4	A4
5	C3	C3	C3
6	A3.5	A3.5	A3.5
7	B2	B2	B2
8	A4	A4	A4
9	A4	A4	A4
10	C2	C2	C2
11	C4	C4	C4
12	A3.5	A3.5	A3.5
13	A4	A4	A4
14	A3.5	A3.5	A3.5
15	A3	A3	A3
16	A3	A3	A3
17	A3.5	A3.5	A3.5
18	A3	A3	A3
19	B1	B1	B1
20	C3	C3	C3
Cochran's Q test	Test not applicable		

Table 1 presents the distribution of tooth shades according to the VITA shade guide and the color stability of monolithic zirconia crowns in Group 0 (non-tobacco users) at baseline, 6 months, and 12 months. All 20 participants exhibited identical VITA shade values at each evaluation period, demonstrating that no detectable color alteration occurred throughout the 12-month follow-up. Since every restoration maintained its original shade without any variation over time, statistical analysis using Cochran's Q test was not applicable.

Table 2: Distribution of VITA tooth shades and evaluation of the color stability of monolithic zirconia crowns in Group 1 (smokers) at baseline, 6-month, and 12-month follow-up assessments.

Patient no.	Baseline (T0)	After 6 months (T1)	After 12 months (T2)
1	A4	A4	A4
2	C2	C2	C3
3	A3.5	A3.5	A3.5
4	A3.5	A3.5	C3
5	A3	A3	B3
6	A3.5	A3.5	A3.5
7	A3.5	A3.5	C4
8	B1	B1	B2
9	C4	C4	C4
10	A2	A2	A3
11	A3	A3	A3.5
12	A3.5	A3.5	A3.5
13	A3.5	A3.5	A4
14	C3	C3	C4
15	A3.5	A3.5	A3.5
16	A3	A3	A3.5
17	C2	C2	C3
18	B2	B2	B3
19	A3.5	A3.5	A4
20	C2	C2	C3
Cochran's Q test	Cochran's Q = 28.000, df = 2, P = 0.000 (<0.05), Significant		
McNemar test (Pairwise comparison with Bonferroni correction)	Baseline (T0) and After 6 months (T1): Test not applicable Baseline (T0) and After 12 months (T1): P = 0.000 (<0.017), Significant After 6 months (T1) and After 12 months (T1): P = 0.000 (<0.017), Significant		

Table 2 Summarizes the distribution of VITA tooth shades and the color stability of monolithic zirconia crowns in Group 1 (smokers) at baseline, 6 months, and 12 months. No alteration in VITA shade was observed between baseline and the 6-month follow-up. However, by the end of the 12-month evaluation, 14 of the 20 participants (70%) demonstrated a transition to darker VITA shades, indicating a progressive reduction in color stability among smokers.

Statistical analysis using Cochran's Q test revealed a significant difference in shade distribution across the three evaluation periods ($Q = 28.000$, $df = 2$, $P < 0.05$). Subsequent pairwise comparisons using the McNemar test with Bonferroni correction showed no statistically analyzable difference between baseline and the 6-month follow-up. In contrast, significant shade changes were identified between baseline and 12 months ($P < 0.017$) as well as between 6 months and 12 months ($P < 0.017$), demonstrating a gradual increase in discoloration during the 12-month observation period among smokers.

Table 3: Distribution of VITA tooth shades and assessment of the color stability of monolithic zirconia crowns in Group 2 (smokeless tobacco users) at baseline, 6-month, and 12-month follow-up intervals.

Patient no.	Baseline (T0)	After 6 months (T1)	After 12 months (T2)
1	A4	A4	A4
2	C3	C3	C4
3	C3	C3	C4
4	B4	B4	C4
5	A3.5	A3.5	B4
6	C2	C2	C3
7	A4	A4	A4
8	A3	A3	A3.5
9	A3	A3	A3
10	A4	A4	A4
11	A4	A4	A4
12	A3.5	A3.5	A4
13	A3.5	A4	A4
14	A4	B4	B4
15	A2	A3.5	A3.5
16	C2	C2	C3
17	B2	B2	B3

18	A3	A3	A3.5
19	A2	A3	A3
20	A2	A2	A3
Cochran's Q test	Cochran's Q = 24.133, df = 2, P = 0.000 (<0.05), Significant		
McNemar test (Pairwise comparison with Bonferroni correction)	Baseline (T0) and After 6 months (T1): P = 0.125 (>0.017), not significant Baseline (T0) and After 12 months (T1): P = 0.000 (<0.017), Significant After 6 months (T1) and After 12 months (T1): P = 0.001 (<0.017), Significant		

Table 3 Illustrates the distribution of VITA tooth shades and the color stability of monolithic zirconia crowns in Group 2 (smokeless tobacco users) at baseline, 6 months, and 12 months. At the 6-month evaluation, color alteration was detected in 4 participants (20%) compared with baseline. This proportion increased substantially by the 12-month follow-up, with 15 participants (75%) exhibiting a shift toward darker VITA shades, indicating a progressive decline in shade stability among smokeless tobacco users.

Analysis using Cochran's Q test demonstrated a statistically significant difference in shade status across the three assessment periods ($Q = 24.133$, $df = 2$, $P < 0.05$). Pairwise comparisons performed with the McNemar test and Bonferroni correction revealed that the difference between baseline and the 6-month follow-up was not statistically significant ($P = 0.125$; $P > 0.017$). However, significant changes in shade were observed between baseline and 12 months ($P = 0.000$; $P < 0.01$) as well as between the 6-month and 12-month evaluations ($P = 0.001$; $P < 0.017$), indicating continued and significant discoloration during the latter half of the follow-up period.

Table 4: Distribution of VITA tooth shades and assessment of the color stability of monolithic zirconia crowns in Group 3 (dual tobacco users) at baseline, 6-month, and 12-month follow-up intervals.

Patient no.	Baseline (T0)	After 6 months (T1)	After 12 months (T2)
1	A4	C4	C4
2	A4	C3	C3
3	B1	B1	B3
4	A4	A4	C4
5	B4	B4	C4
6	C4	C4	C4
7	A3.5	A3.5	A4
8	A3.5	A3.5	A3.5
9	A4	A4	C2
10	C3	C3	C4
11	B1	B1	B3
12	A3.5	A4	A4
13	D3	D3	D4
14	B4	B4	C4
15	C2	C2	C3
16	B2	B2	B3
17	C2	C3	C4
18	A3	A3	A4
19	B2	B2	B3
20	C2	C2	C3
Cochran's Q test	Cochran's Q = 31.000, df = 2, P = 0.000 (<0.05), Significant		
McNemar test (Pairwise comparison with Bonferroni correction)	Baseline (T0) and After 6 months (T1): P = 0.250 (>0.017), not significant Baseline (T0) and After 12 months (T1): P = 0.000 (<0.017), Significant After 6 months (T1) and After 12 months (T1): P = 0.000 (<0.017), Significant		

Table 4 Presents the distribution of VITA tooth shades and the evaluation of color stability in Group 3 (dual tobacco users) at baseline, 6 months, and 12 months. At the 6-month follow-up, shade alteration was identified in 3 participants (15%) compared with baseline. By the end of the 12-month observation period, this number increased markedly, with 18

participants (90%) exhibiting a transition to darker VITA shades, indicating the greatest reduction in color stability among all study groups.
The results of Cochran's Q test demonstrated a statistically significant variation in shade status across the three evaluation periods ($Q = 31.000$, $df = 2$, $P < 0.05$). Pairwise comparisons using the McNemar test with Bonferroni correction showed that the difference between baseline and the 6-month assessment was not statistically significant ($P > 0.017$). However, significant changes were observed between baseline and 12 months ($P < 0.017$) as well as between the 6-month and 12-month follow-up periods ($P < 0.017$), confirming a substantial increase in discoloration during the latter half of the study among dual tobacco users.

Within-group analysis performed using Cochran's Q test revealed significant temporal changes in shade stability among smokers, smokeless tobacco users, and dual tobacco users ($P < 0.05$). Further pairwise analysis demonstrated that significant color changes occurred between baseline and 12 months and also between the 6-month and 12-month evaluations in each of the tobacco-user groups, indicating progressive discoloration with prolonged tobacco exposure.

Comparison of shade stability between the study groups at the 6-month follow-up showed no statistically significant difference ($P = 0.238$). In contrast, analysis at 12 months demonstrated a highly significant difference among the four groups ($\chi^2 = 39.768$, $P < 0.001$). Participants in the non-tobacco group maintained complete color stability throughout the study period, whereas all categories of tobacco users exhibited progressively greater discoloration over time. Although dual users demonstrated the highest frequency of shade alteration, no statistically significant differences were observed among smokers, smokeless tobacco users, and dual tobacco users. These findings suggest that the cumulative duration of tobacco exposure, rather than the specific mode of tobacco consumption, is the principal factor contributing to the deterioration of shade stability in monolithic zirconia restorations. (Table 5 and 6).

Table 5: Comparison of the color stability of monolithic zirconia crowns among the study groups from baseline to the 6-month follow-up period.

Groups	Shade Stability		Total n (%)
	Yes n (%)	No n (%)	
Group 0 (Non-tobacco users)	20 (100.00)	00 (0.00)	20 (100.00)
Group 1 (Smokers)	20 (100.00)	00 (0.00)	20 (100.00)
Group 2 (Smokeless tobacco users)	16 (80.00)	04 (20.00)	20 (100.00)
Group 3 (Dual users)	17 (85.00)	03 (15.00)	20 (100.00)
Chi-square test	Yates' $\chi2 = 4.227$, $df = 3$, $P = 0.238$ (> 0.05), Not significant		

Table 5 Summarizes the inter-group comparison of the color stability of monolithic zirconia crowns from baseline to the 6-month follow-up among the four study groups. Complete shade stability was observed in Group 0 (non-tobacco users) and Group 1 (smokers) , with all 20 participants (100%) in each group showing no detectable color change at 6 months. In Group 2 (smokeless tobacco users) , 16 participants (80.00%) retained their original shade, whereas 4 participants (20.00%) exhibited a change in shade. Similarly, in Group 3 (dual tobacco users), shade stability was maintained in 17 participants (85.00%), while 3 participants (15.00%) demonstrated shade alteration. Statistical analysis using Yates' Chi-square test indicated that the differences in shade stability among the four groups at the 6-month follow-up were not statistically significant ($\chi^2 = 4.227$, $df = 3$, $P > 0.05$).

Table 6: Inter-group comparison of the color stability of monolithic zirconia crowns between baseline and the 12 months follow-up period.

Groups	Shade Stability		Total n (%)
	Yes n (%)	No n (%)	
Group 0 (Non-tobacco users)	20 (100.00)	00 (0.00)	20 (100.00)
Group 1 (Smokers)	06 (30.00)	14 (70.00)	20 (100.00)
Group 2 (Smokeless tobacco users)	05 (25.00)	15 (75.00)	20 (100.00)
Group 3 (Dual users)	02 (10.00)	18 (90.00)	20 (100.00)
Chi-square test (Overall)	$\chi2 = 39.768$, $df = 3$, $P = 0.000$ (<0.05), Significant		
Chi-square test (Pairwise comparison with Bonferroni correction)	Non-tobacco user and Smokers: $\chi2 = 21.538$, $df = 1$, $P = 0.000$ (<0.008), Significant Non-tobacco user and Smokeless tobacco users: $\chi2 = 24.000$, $df = 1$, $P = 0.000$ (<0.008), Significant Non-tobacco user and Dual users: $\chi2 = 32.727$, $df = 1$, $P = 0.000$ (<0.008), Significant Smokers and Smokeless tobacco users: $\chi2 = 0.125$, $df = 1$, $P = 0.724$ (>0.008), Not significant Smokers and Dual users: Yates' $\chi2 = 1.406$, $df = 1$, $P = 0.236$ (>0.008), Not significant		

	Smokeless tobacco users and Dual users: Yates' $\chi 2 = 0.693$, df = 1, P = 0.405 (>0.008), Not significant

Table 6 Presents the inter-group comparison of the color stability of monolithic zirconia crowns from baseline to the 12-month follow-up among the four study groups. At the end of the 12-month observation period, all participants in Group 0 (non-tobacco users) maintained their original VITA shade, demonstrating 100% shade stability. In contrast, Group 1 (smokers) showed shade stability in only 6 participants (30.00%), while 14 participants (70.00%) exhibited discoloration. Similarly, Group 2 (smokeless tobacco users) had 5 participants (25.00%) who retained their original shade, whereas 15 participants (75.00%) experienced a change in shade. The greatest degree of discoloration was observed in Group 3 (dual tobacco users) , where only 2 participants (10.00%) maintained shade stability and 18 participants (90.00%) demonstrated a shift to darker VITA shades.

The overall inter-group comparison using the Chi-square test revealed a highly statistically significant difference in shade stability among the four groups ($\chi^2 = 39.768$, df = 3, $P < 0.05$). Post hoc pairwise analysis with Bonferroni correction showed that the non-tobacco group differed significantly from each of the tobacco-user groups, including Group 1 (smokers) ($\chi^2 = 21.538$, $P < 0.008$), Group 2 (smokeless tobacco users) ($\chi^2 = 24.000$, $P < 0.008$), and Group 3 (dual tobacco users) ($\chi^2 = 32.727$, $P < 0.008$). However, no statistically significant differences were identified among the three tobacco-user groups. Comparisons between Group 1 and Group 2 ($\chi^2 = 0.125$, $P > 0.008$), Group 1 and Group 3 ($\chi^2 = 1.406$, $P > 0.008$), and Group 2 and Group 3 ($\chi^2 = 0.693$, $P > 0.008$) were not significant, indicating that irrespective of the form of tobacco consumed, tobacco exposure produced a comparable adverse effect on the long-term color stability of monolithic zirconia restorations.

CONCLUSION

Monolithic zirconia crowns maintained excellent color stability during the initial 6-month follow-up irrespective of tobacco-use status. Nevertheless, extended exposure to tobacco resulted in a significant decline in long-term color stability, with progressive discoloration becoming evident after 12 months in smokers, smokeless tobacco users, and dual tobacco users. In contrast, restorations placed in non-tobacco users retained their original shade throughout the entire study period.

The results of this investigation suggest that the deterioration in shade stability of monolithic zirconia restorations is more closely associated with the cumulative duration of tobacco exposure than with the specific type of tobacco consumed. Among the tobacco-user groups, individuals with combined smoking and smokeless tobacco habits exhibited the greatest degree of discoloration, indicating an additive effect of dual tobacco use. These findings emphasize that tobacco consumption should be regarded as an important prognostic consideration during prosthodontic treatment planning and while counseling patients regarding the expected long-term esthetic performance of monolithic zirconia restorations.

Clinical Implications

Although monolithic zirconia restorations demonstrate excellent initial esthetic performance, their long-term color stability may be adversely affected by persistent tobacco use. Accordingly, assessment of a patient's tobacco-use history should form an integral part of treatment planning, restorative material selection, and the informed consent process. Patients should also be advised about the increased likelihood of restoration discoloration associated with continued tobacco consumption and encouraged to maintain meticulous oral hygiene, undergo periodic professional polishing and maintenance, and pursue tobacco cessation measures to optimize the long-term esthetic success of their restorations.

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Declaration of Interest

None

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REFERENCES

1. Anusavice KJ. Phillips' science of dental materials.12th ed. St. Louis: Elsevier; 2013.
2. Denry I, Kelly JR. State of the art of zirconia for dental applications. Dent Mater. 2008;24(3):299-307.
3. Piconi C, Maccauro G. Zirconia as a ceramic biomaterial. Biomaterials. 1999;20(1):1-25.
4. Sailer I, Pjetursson BE, Zwahlen M, Hämmerle CH. A systematic review of the survival and complication rates of all-ceramic and metal-ceramic reconstructions after an observation period of at least 3 years. Part II: fixed dental prostheses. Clin Oral Implants Res. 2007;18 Suppl 3:86-96.
5. Guess PC, Att W, Strub JR. Zirconia in fixed implant prosthodontics. Clin Implant Dent Relat Res. 2012;14(5):633-645.
6. Zhang Y. Making yttria-stabilized tetragonal zirconia translucent. Dent Mater. 2014;30(10):1195-1203.
7. Johnston WM. Color measurement in dentistry. J Dent. 2009;37 Suppl 1:e2-e6.
8. Joiner A. Tooth colour: a review of the literature. J Dent. 2004;32 Suppl 1:3-12.
9. Watts A, Addy M. Tooth discolouration and staining: a review of the literature. Br Dent J. 2001; 190(6):309-316.
10. Nathanson D. Surface staining mechanisms of dental restorative materials. J Esthet Dent. 1997;9(4):215- 220.
11. World Health Organization. Global adult tobacco survey: India fact sheet. Geneva: World Health Organization; 2017.

12. Al-Hiyasat AS, Darmani H, Elbetieha AM. Effects of smoking on dental restorative materials. J Prosthet Dent. 2002;88(4):420-424.
13. Bansal R, Singh R, Kaur K, Sharma D. Effects of smokeless tobacco on oral tissues and dental structures. Indian J Dent Res. 2010;21(4):559-563.
14. Vichi A, Ferrari M, Davidson CL. Color and opacity variations in three different resin-based composite products after water aging. Dent Mater. 2011;
27(1):29-38.
15. Subaşı MG, İnan Ö, Alkumru HN. Effect of surface treatments and resin cement selection on bonding to zirconia. J Prosthet Dent. 2014;111(6):465-471.
16. Acar O, Yilmaz B, Altintas SH, Chandrasekaran I, Johnston WM. Color stainability of CAD/CAM and nanocomposite resin materials. J Prosthet Dent.
2016;115(1):71-75.
17. Ertaş E, Güler AU, Yücel AC, Köprülü H, Güler E. Color stability of resin composites after immersion in different drinks. Dent Mater J. 2006;25(2):371-376.
18. Kurt M, Ural Ç, Kulunk T, Kulunk Ş, Baba S. Color stability of monolithic zirconia after accelerated aging. J Prosthet Dent. 2019;121(4):635-640.
19. Hickel R, Roulet JF, Bayne S, Heintze SD, Mjör IA, Peters M, et al. Recommendations for conducting controlled clinical studies of dental restorative materials. Dent Mater. 2013;29(1):28-43.
20. VITA Zahnfabrik. VITA Easyshade V technical manual. Bad Säckingen: VITA Zahnfabrik; 2017.
21. Paravina RD, Ghinea R, Herrera LJ, Bona AD, Igiel C, Linninger M, et al. Color difference thresholds in dentistry. J Esthet Restor Dent. 2015;27 Suppl 1:S1-S9