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Effectiveness of low-viscosity resin infiltration (Icon) on color change of enamel white spot lesions: 1-year follow-up clinical study

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Abstract

Background To evaluate the effect of the low-viscosity Icon resin infiltrate application on the color change of white spot enamel lesions (WSLs) over 3-, 6-, and 12-m follow-up periods.

Methods Ninety-six teeth diagnosis with WSLs using the ICDAS scoring system in 49 participants were assessed for their color change using the Icon resin infiltration technique. The Icon kit was applied to WSLs as instructed by the manufacturer. Icon-Etch (15% hydrofluoric acid) was applied to the lesions for 2 min, and then, it was rinsed off with copious amount of water for 30 s. Then, Icon-Dry (99% ethanol) was applied to the etched lesions for 30-s followed by the application of the Icon resin infiltrate that was light cured for 40 s. Color change assessment was performed using Vita Easyshade V spectrophotometer at baseline and immediately after Icon resin infiltration, then at 3-, 6-, and 12-m follow-up periods. Analysis of the data was performed using the test of repeated measure ANOVA and the paired sample t test.

Results There was a statistically significant difference in ΔE between the different follow-up periods at immediate, 3-m, 6-m, and 12-m. The highest mean value was found in the immediate follow-up period, while the lowest mean value was found in 12-m follow-up period.

Conclusions Low-viscosity Icon resin infiltration has the ability for immediate diffusion into the WSLs giving an immediate improvement in the esthetic outcome of the WSLs. However, its long-term outcomes might not be consistent for the color change of the WSLs.

Keywords Low-viscosity resin infiltration, Icon, Color change, Enamel white spot lesions, Clinical study

Background

Esthetic dentistry has drawn a great attention lately among patients seeking a perfect smile. Teeth aesthetics is chiefly presented by their texture, color as well as their enamel translucency. Moreover, the quality of anterior teeth enamel presents an important factor for patients' satisfaction with their smile and appearance. However, early caries may go undetected until it manifests clinically as a dull, slightly rough enamel surface with areas that are brown or chalky and lack cavitation.

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Such localized detectable surface and subsurface enamel demineralization has been reported as white spot lesions (WSLs) (Puleio et al. 2022).

WSLs could be developed from idiopathic causes, developmental causes as fluorosis, or from early caries (Gohar et al. 2023; Klaisiri et al. 2020; Liu et al. 2023; Patano et al. 2023). Furthermore, WSLs could be efficiently diagnosed using a visual examination method known as the 'International Caries Detection and Assessment System' (ICDAS) at multiple clinical caries stages with a high degree of precision. The ICDAS scoring system was proposed for meticulous caries assessment and detection of the early enamel lesions appearing after through dryness of the teeth surfaces without cavitation, and it has a scoring system rages from 0 to 6 (Alves et al. 2018).

The typical treatment for early enamel lesions is to promote the remineralization of such lesions (Abdelnabi et al. 2020; Hamdy 2018; Lamiaa Mahmoud Moharam et al. 2020; Zaki et al. 2021) Additionally, several approaches had been proposed to improve WSLs aesthetic appearance (Lazar et al. 2023; Lopes et al. 2024). It is noteworthy that the depth and activity of WSLs strongly affects the followed treatment protocol. The activity of the WSLs is directly associated with their clinical appearance. Usually, a chalky-white appearance with a rough surface could be detected with gentle probing of the active lesions (Amend et al. 2022). On the other hand, the inactive lesions tend to appear brighter with a smooth surface with gentle probing. The natural salivary remineralization effect or the use of remineralizing chemicals like CPP-ACP (Casien phosphopeptide–amorphous calcium phosphate) and fluoride varnishes can be used to treat mildly active WSLs (Hamdy et al. 2020), while the moderate and severe active lesions can be treated in different ways such as micro abrasion, or veneers (Kannan and Padmanabhan 2019). Unfortunately, such treatment modalities have several drawbacks as their liability for staining during the remineralization process, immediate unsatisfactory results, patient compliance requirement, or being an invasive treatment. Furthermore, it was reported that CPP-ACP and fluoride varnishes can only cause superficially remineralization; meanwhile, the depth of the lesion is still porous, which might adversely affect the final aesthetic outcome of the concerned teeth (Cazzolla et al. 2018).

Minimal intervention treatment methods of WSLs could have led to a major enhancement in their aesthetic appearance as well as a noticeable regression of the lesions (Pomacóndor-Hernández and Hernandes Da Fonseca 2020). Flowable resin composites represent the most convenient resinous material regarding the minimal invasive concept (Abdelraouf et al. 2019; Hamdy 2017, 2021). This fact is mainly refereed to their lower viscosity and filler content, which impart a higher penetration power (Kobbe et al. 2019; Zaki et al. 2021). Infiltration of hypo-calcified or demineralized porous enamel with a low-viscosity resin could alter their refractive index, to be closer to that of the tooth, hence improve esthetic (Kobbe et al. 2019).

Icon resin infiltration has been recently introduced by developing a highly flowable resinous material that was proved to cause an immediate aesthetic masking of mild WSLs to match the adjacent sound enamel (Kanar et al. 2024). It was reported that Icon resin infiltration could be applied without significant color change up to 6 months (Knösel et al. 2019). It is a noninvasive technique that offers an intermediate treatment option between the restorative and preventive therapies. The mechanism of action of Icon resin infiltration is to use capillary action to pierce the porous enamel surface and occlude the micro porosities in the enamel, so that the lesion progression would be arrested and the pathway for further acid diffusion would be blocked (Aziznezhad et al. 2017; Shimada et al. 2020).

The most important task for Icon resin infiltration is to eliminate the enamel's outer, hyper-mineralized layer. Surface conditioning is therefore crucial because the hyper-mineralized layer on the surface may prevent resin from penetrating the depth of the surface lesion (Soveral et al. 2021). In order to evaluate the effectiveness of the Icon resin infiltration technique on the color change of WSLs at 3-, 6-, and 12-m follow-up periods, a clinical investigation was carried out. According to the null hypothesis, there would be no impact of Icon resin infiltration on the color change of WSLs during the various follow-up periods.

Methods

Ethical approval and informed consents

This clinical investigation was registered in accordance with the Consolidated Standards of Reporting Trials (CONSORT) Statement and assigned the identification number NCT05757440 in the www.clinicaltrials.gov database. The ethics of this clinical investigation were guided by the General Assembly's October 2013 Declaration of Helsinki (World Medical Association 2013). The National Research Centre (NRC) in Cairo, Egypt's Medical Research Ethical Committee (MREC) accepted the current study (Reference number: 20157). Every subject provided verbal informed consent, and all legal guardians were requested to sign a formal informed consent form.

Study design and setting

In this single-arm non-randomized follow-up clinical investigation, 48 students from eight public secondary

schools in Greater Cairo, Egypt, whose socioeconomic status ranged from lower middle to lower, participated. The research was conducted between January 2020 and June 2022, spanning two academic years (2020–2022). The study was supposed to be finished in a single academic year; however because of COVID-19 precautions, all schools were closed for a specific amount of time when the outbreak peaked.

Eligibility criteria

Eight Egyptian public secondary school students who met the following inclusion criteria were chosen to participate in this clinical study: they had to be between the ages of 14 and 18; they also needed to be in good general health; have a permanent dentition; have healthy anterior teeth; and had non-cavitated WSLs. Present orthodontic treatments, retained teeth, congenital or developmental anomalies in the permanent dentition, systematic conditions, smoking, poor oral hygiene, general health issues, missing anterior teeth, carious anterior teeth, intrinsic and extrinsic staining, and anterior restorations were among the exclusion criteria.

Demographic data

All of the Egyptian teenagers who signed up for the study belonged to the same ethnic group. The age range was 14–18 years old, with a mean age of 16.10 years. The following methods were used to fairly recruit both single male and female students for the current study. The demographic data's mean, standard deviation (SD), and frequencies were computed.

Sample size calculation

The primary objective of this research was to assess the Icon resin Infiltration's color change at 3-, 6-, and 12-month intervals. The application of Icon resin infiltration would not impact the color change of WSLs at the three investigated follow-up periods, according to the null hypothesis, which was examined statistically using a power analysis that was created to have sufficient power. After determining an effect size (dz) of (0.681) based on the findings of earlier research (Cazzolla et al. 2018), the alpha (α) level of (0.05) and beta (β) level of (0.2) are observed. The minimal required sample size was found to be 96 anterior teeth with WSLs ($n_{\text{teeth}} = 96$). When 96 anterior teeth with WSLs were included in the investigation, the study power reached 80%. In order to compensate for any patient dropouts that occurred throughout the follow-up periods, the total number of participants in the investigation was increased by 15%, or 57 people. *G*Power* 3.1.9.7 was used to calculate the sample size.

Participants enrollment

A well-informed consent form was signed by legal guardians of all participants prior to the start of the trial. Fifty-seven subjects aged between 14-y and 18-y who fulfilled the eligibility criteria were diagnosed with WSLs according to Tufekci et al. (2011). This clinical study was conducted at the National Research Centre dental outpatient clinic. However, only 49 participants ($n_{\text{participant}} = 49$) with 96 teeth diagnosed with WSLs ($n_{\text{teeth}} = 96$) had completed the study at all follow-up periods after patients drop out.

Diagnostic procedures for WSLs detection

The non-restored permanent anterior teeth of the participants were visually examined for the existence of WSLs according to the ICDAS criteria to the dry and clean teeth surfaces, where a score was provided to the affected surface to signify the caries level as described in Table 1 (Noaman 2019; Zaazou et al. 2023). Only scores 1, 2, and 3 of the ICDAS criteria were employed for the current study.

Icon resin infiltration application procedures

When necessary, the participants used a hand scaler to remove dental calculus and plaque from the tooth surfaces during the cleaning and polishing operations. After that, all teeth with WSLs were polished using a rubber cup and

Table 1 ICDAS scoring system for the caries level of the teeth with WSLs

Score	Criteria
0	Sound tooth surface with no evidence of caries after air dryness for 5-s
1	First visual enamel change with visible opacity or white/brown discoloration after prolonged air dryness (not or barely noticed on wet surfaces)
2	Distinct visual enamel change with opacity or discoloration that is clearly visible on wet surfaces. The lesion has to be discernible after air dryness (at pit and fissure entrance)
3	Localized enamel breakdown due to caries with no visible dentine or underlying shadow, with evident opacity or discoloration (wider than the natural fissure/fossa) on wet and dry tooth surface
4	Underlying dark shadow from dentine with or without localized enamel breakdown
5	Evident cavitation with visible underlying dentine indicating visual evidence of demineralization and exposed dentine
6	Extensive cavitation with visible dentine and more than 1/2 of the surface is engaged

fluoride-free polishing paste to remove any external stains. Next, a rubber dam was properly applied and isolated using cotton rolls to safeguard the surrounding soft tissues and to guarantee a dry field. Finally, the teeth were allowed to air dry for 5-s (Cazzolla et al. 2018; World Medical Association 2013). As directed by the manufacturer, Icon-Etch (Chemisch-Pharmazeutische, Fabrik GmbH, Elbgaustraße, Hamburg, Germany) was applied exclusively to the designated areas of WSLs for a duration of 2 min in order to remove the hyper-mineralized enamel surface layer that could obstruct the subsequent resin penetration. Icon-Etch is made up of 15% hydrochloric acid, pyrogenic silicic acid, water, and additives. The next step was to rinse thoroughly with water for at least 30 s, and then to dry completely in the air without using any oil. Subsequently, the same region was treated with 99% ethanol Icon-Dry (Chemisch-Pharmazeutische, Fabrik GmbH, Elbgaustraße, Hamburg, Germany) for 30 s, and air drying was then performed. A visual assessment was performed to gauge the extent of color shift. The later step previewed the esthetic result that could be obtained after resin infiltration. However, those earlier procedures might be carried out four more times in order to achieve a color change that was suitable. After applying Icon-Dry for three minutes, which produced good aesthetic effects, Icon resin was applied using the included sponge applicator and vigorous rubbing to the surface. It was then light cured for 40 s as the manufacturer advised (Abbas et al. 2018; Cazzolla et al. 2018; Knösel et al. 2019) using a 3 M ESPE, USA, LED light curing system (Elipar S 10). The light curing unit's intensity was less than 1000/cm^2.

Color change assessment

The WSLs' color was measured immediately prior to resin infiltration (baseline E0), then directly after the resin infiltration ($\Delta E1$), and it was recorded after 3-, 6-,12-m follow-up periods ($\Delta E3$, $\Delta E6$, $\Delta E12$, respectively)(Knösel et al. 2019) utilizing an intraoral spectrophotometer, VITA Easyshade® V (VITA Zahnfabrik, Bad Sackingen, Germany) (ElAziz et al. 2022; Kannan and Padmanabhan 2019). The CIELAB color difference measuring formula ΔE of Munsell system was used to record the color change of the WSLs at the different follow-up periods. Every follow-up period's mean measurement was computed using three recorded values for every WSL. The following equation was used to calculate the color difference (ΔE) values: (ElAziz et al. 2022; Soveral et al. 2021)

$$\Delta E*_{\mathrm{Lab}} = \left[\left(\Delta L^2\right) + \left(\Delta a^2\right) + \left(\Delta b^2\right)\right]^{1/2}$$

where a value of 100 denotes a perfect white and a value of zero denotes a perfect black, the L^* value indicates the lightness of an object. The degree of greenness is indicated by negative $a^* - 80$, and the degree of redness by positive a^* value + 80. Lastly, the blueness of the b^* value indicates negative $b^* - 80$, and the yellowness of the value indicates the degree where positive $b^* + 80$. The smaller the ΔE, the smaller the color difference between the tooth's ultimate color and its original color measurement (Soveral et al. 2021). WSLs photographs were taken at the baseline and at each follow-up appointment ($\Delta E1$, $\Delta E3$, $\Delta E6$ and $\Delta E12$), and the size and location of the WSLs were mapped at E0 to permit correct assessment at each follow-up period (Soveral et al. 2021).

Four operators were assigned to perform the resin infiltration application procedures as well as the color change assessment following the exact manufacturers' instructions. Additionally, two independent observers with normal color vision according to Ishiara test were selected to be responsible for confirmation of the color change assessment at the same visit of the determined follow-up periods (Nagi and Moharam 2022) under the circumstances reported by Abdelraouf and Habib (2016), Abdelraouf and Habib (2016), El-Rashidy et al. (2022).

Statistical analysis

For every test, each group's mean and standard deviation were computed. A parametric (normal) distribution was observed in the data after they were examined for normality using the Kolmogorov–Smirnov and Shapiro–Wilk tests. More than two groups in linked samples were compared using the ANOVA test. Two groups in related samples were compared using the paired sample t test. Set at $P < 0.05$ was the significance threshold. Use of IBM® SPSS® Statistics version 20 for Windows was used for statistical analysis.

Results

Participants in the current follow-up clinical investigation were drawn from eight public secondary schools located in Greater Cairo, Egypt. The age, frequency, and gender percentage mean and standard deviation (SD) statistics are displayed in Table 2. The findings indicated that 49 people were a part of the research. Female participants presented 61.22% (30), while male participants presented 38.77% with 16.10 y average age.

Results of inter-observer reliability

The findings of the inter-observer reliability test indicated that there was a non-statistically significant difference between the color readings at $p = 0.55$. The complete set of color readings showed an inter-class correlation coefficient (ICC) more than 0.9, indicating strong agreement and dependability between the various examiners' color readings.

Table 2 Standard deviation (SD) and mean values and the demographic data frequency of the participants of the current study

Variables		Demographic data		
		Mean/n	SD/%	p-value
Age (Years)		16.10	1.33	-
Gender (n, %)	Females	30	61.22%	< 0.001*
	Males	19	38.77%	

ns; Nonsignificant ($p > 0.05$)

Table 4 The mean and standard deviation of ΔE at each of the various follow-up intervals

Variables	Δ*E*	
	Mean	SD
Immediate (*E*1)	8.49	2.41
3-m follow-up (*E*3)	7.88	2.59
6-m follow-up (*E*6)	7.31	2.62
12-m follow-up (*E*12)	6.97	2.66
p-value	< 0.001*	

* Significant ($p < 0.05$)

Table 3 displays pairwise comparisons of the impact of the current study's four follow-up periods (immediate, 3-, 6-, and 12-m) on the WSLs' color change. When the level of significance was set at 0.05, a pairwise comparison of the various groups of the examined factor (follow-up periods) showed that there was a statistically significant difference among the estimated marginal means of the various follow-up periods.

There was a statistically significant difference in ΔE between the immediate, 3-, 6-, and 12-month follow-up periods, as shown in Table 4 and Fig. 1, with $p < 0.001$. There was a substantial statistical difference in Δ*E* between the Immediate group and the 3-, 6-, and 12-m groups, with $p < 0.001$. Furthermore, $p < 0.001$ indicated a statistically significant difference in Δ*E* between the 3- and each of the 6- and 12-m groups. Between the 6- and 12-m groups, there was a statistically significant difference ($p < 0.001$). The 12-m group had the lowest mean value, while the immediate group had the greatest mean value.

Discussion

Although white spot enamel lesions are thought to be a prevalent aesthetic issue, their true cause—which goes beyond their outward white appearance—is mineral loss, which can be mixed, superficial, or deep. Because of the loss of minerals, the enamel becomes porous and has more pore space inside the lesion's body, which detracts from its aesthetic appeal (Abdullah and John 2016; Saluja et al. 2022). This in turn might change the optical properties to opaque white appearance enamel lesion (Saluja et al. 2022). Moreover, WSLs may be due to carious or developmental attacks during enamel formation (Pomacóndor-Hernández and Hernandes Da Fonseca 2020).

Table 3 Pairwise comparisons of the predicted marginal means during the various research follow-up periods and how they affected the WSLs' color change

Measures						
(I) Factor		Mean difference (I-J)	Std. Error	Sig.[a]	95% confidence interval for difference[b]	
					Lower bound	Upper bound
Immediate	3-m	0.610*	0.106	0.000	0.396	0.824
	6-m	1.180*	0.151	0.000	0.876	1.484
	12-m	1.520*	0.171	0.000	1.174	1.866
3-m	Immediate	−0.610*	0.106	0.000	−0.824	−0.396
	6-m	0.570*	0.093	0.000	0.383	0.757
	12-m	0.910*	0.105	0.000	0.697	1.123
6-m	Immediate	−1.180*	0.151	0.000	−1.484	−0.876
	3-m	−0.570*	0.093	0.000	−0.757	−0.383
	12-m	0.340*	0.056	0.000	0.227	0.453
12-m	Immediate	−1.520*	0.171	0.000	−1.866	−1.174
	3-m	−0.910*	0.105	0.000	−1.123	−0.697
	6-m	−0.340*	0.056	0.000	−0.453	−0.227

*At the 0.05 level, the mean difference is significant

[a] Multiple comparison adjustment: Least significant difference, or no modifications

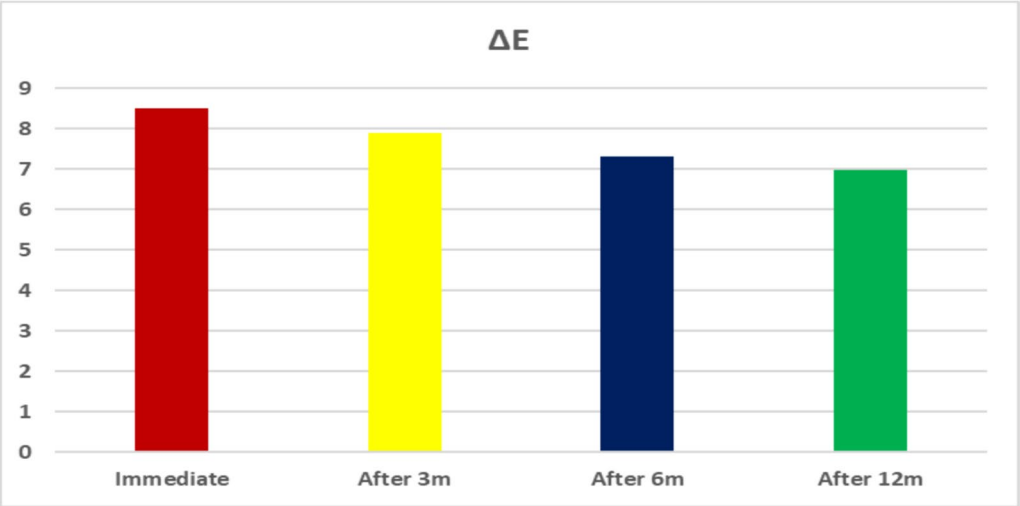

Fig. 1 Bar graphs displaying E for various groups at various intervals of follow-up

The depth and type of WSLs plays a critical role in decision making of the most suitable line of treatment and hence the durability of the obtained results. Achieving a satisfactory cosmetic outcome while remaining as conservative as feasible is the aim of clinical care for these types of lesions. Numerous therapeutic approaches have been proposed to address these instances. Icon resin infiltration technique is not only the most conservative and noninvasive technique but also the most successful esthetic modality that perfectly masks the WSLs as well (Makkar and Gupta 2015). Beyond its aesthetic camouflage effect, the cause is infiltration of the low-viscosity resin into the pores of WSLs, which has a refractive index similar to that of enamel (Cazzolla et al. 2018; Ebrahimi et al. 2017). Cazzolla et al. 2018 (Cazzolla et al. 2018) stated that Icon resin infiltration inside the porous WSLs could mechanically strengthen it by preventing the caries process to occlude the porous enamel. Moreover, it was conveyed by several studies that Icon resin infiltrate has successfully masked the WSLs, and it can be considered as the gold standard for masking WSLs (Abdullah and John 2016; Knösel et al. 2019; Perlea et al. 2017), which could be owed to its low-viscosity that enables it to penetrate efficiently into the porous enamel layers of the WSLs.

The manufacturer of Icon resin infiltration advises applying Icon-Etch (15% hydrochloric acid) first in order to remove the WSLs' surface hyper-mineralized layer and achieve a penetration depth of up to 58 ± 37 µm. Hence, the body of the lesion could be reached to allow for proper resin infiltration that might be able to occlude the previously patent enamel pores. With a refractive index of almost 1.44, the Icon resin is quite similar to sound enamel (1.63).

Additionally, Makkar and Gupta (2015) stated that active lesions have a thin, porous surface layer which can be easily infiltrated by a low-viscosity resin. According to its manufacturer, Icon-Dry (99% ethyl alcohol) should then be used after the etching step to allow for total water evaporation and confirm erosion of the surface layer.

Color change of the desiccated lesions after ethanol application is highly anticipated. However, in cases of deep lesions, thick hyper-mineralized surface layer, or inactive lesions, the repetition of those steps is needed (Makkar and Gupta 2015; Son et al. 2011). Abbas et al. (2018) investigated the application frequency of Icon-Etch and Icon-Dry in different types of WSLs and concluded that one etching with one resin infiltrate application was the most suitable protocol in shallow WSLs; however both deep enamel and shallow dentine lesions, single etching with double infiltration could produce acceptable esthetic results with incomplete masking of the WSLs. However, Arnold et al. (2015) recommended to increase etching times for more than 120-s especially for the deeply situated or long-lasting WSLs to obtain satisfactory cosmetic results. Finally, the Icon resin was actively applied to allow its infiltration into the opened enamel pores followed by light curing for 40-s to allow for full photo-curing and stabilization of the diffused resin.

Vita Easyshade V was found to enable color assessment providing a quantitative and accurate data recording; hence, it was the selected method for color assessment. It was mentioned that the spectrophotometer can identify minute variations in ΔE that are invisible to the unaided

eye (ElAziz et al. 2022; Soveral et al. 2021). In order to assess the effectiveness of Icon resin infiltrate in concealing the color of WSLs, Δ*E* was employed to quantify the color difference that was obtained at various intervals, including immediately following the resin infiltration technique, 3-, 6-, or 12-month follow-up periods, and between the baseline group. It was reported that Δ*E* of 3.3 makes a clinical significance such that the color difference can be detected by human eye (Chang et al. 2015).

The spectrophotometer instrument utilized in this study demonstrated much higher interrater agreement values. However, studies have shown that there are some differences in the parameters of various color measuring tools or visual shade systems. Nevertheless, it is essential to define the uniformity and consistency of utilizing such tools previous to the regular use of such devices in the daily dental practice (Moharam et al. 2022; Śmielecka and Dorocka-Bobkowska 2022).

Additionally, the results of this investigation demonstrated a statistically significant color difference between *E*1 and *E*0 (the baseline), with a mean Δ*E*1 of 8.49. This suggests that the WSLs were successfully aesthetically masking with a significant color difference between the baseline (*E*0) color readings and right after Icon resin infiltration application (*E*1). This concurred with Paris et al. (2013), Matteo et al. (2017), Ceci et al. (2017) who proved that Icon resin infiltration could produce an initial positive effect in masking the WSLs to match the color of the normal sound enamel. In the same context, Paris and Meyer-Lueckel (2009) referred such esthetic camouflage effect due to the loss of the white spotted appearance to mimic the sound enamel. However, in contrast to the findings of this investigation, Son et al. (2011) stated that Icon resin infiltration technique failed to remove WSLs completely and they attributed the cause of such a negative result due to the depth of WSLs which was deeply located within the enamel.

The current study's results also demonstrated a substantial difference between *E*3 and *E*0 (baseline) values regarding the stability of the achieved color following a 3-m follow-up period, with Δ*E*3 of 7.88 suggesting a favorable aesthetic outcome. Moreover, Δ*E3* values remained almost unchangeable after 3-m when compared to the immediate results and this in turn might reflect a stable esthetic masking of the WSLs. This was in accordance with other studies (Kannan and Padmanabhan 2019; Paris et al. 2013; Paris and Meyer-Lueckel 2009) which proved that Icon resin infiltration could initially mask the WSLs successfully up to 6-m. Additionally, taking into account the Icon resin infiltration's long-term effects after 6 months, our data also showed a statistically significant difference between *E*6 and *E*0 (the baseline) values, with Δ*E*6 being 7.31, which may suggest a successful aesthetic outcome. Nevertheless, a statistically significant difference between the Δ*E*6 and Δ*E*1 values was observed, demonstrating a slight but significant negative color change over time. This change could be attributed to the Icon resin's inability to penetrate all the way down into WSLs that may have deep enamel loss. Yet, this difference could still be considered within the accepted range. This was in accordance with Kannan and Padmanabhan (2019), Knösel et al. (2019) who found that, following a 6-month follow-up, WSLs infiltrated with Icon resin exhibited aesthetic effects that were both acceptable and stable as compared to the nearby sound enamel. However, Matteo et al. (2017), Ceci et al. (2017) found that over time, the WSLs treated with Icon resin might become increasingly discolored. Given this, Paris et al. (2013) demonstrated that, in comparison with regular enamel, Icon resin penetration could effectively hide the WSLs and resisted discoloration after treatment.

Regarding the long-term esthetic results after 12-m follow-up period, our results revealed a statistical and significant difference between *E*12 and *E*0 (baseline) values where Δ*E12* was 6.97 indicating a significant color shift. The 12-month follow-up period revealed a marginally significant change in color with time, as demonstrated by the difference between the Δ*E*12 and Δ*E*1 values. These results agreed with those of Matteo et al. (2017), Ceci et al. (2017) who stated that infiltration of the WSLs with Icon resin was not a durable esthetic treatment option, which could be owed to the Icon resin infiltration that was only able to occlude the acid etch pathways (Bisht et al. 2022) and was not able to remineralize the whole demineralized depth of the WSLs (Kannan and Padmanabhan 2019). However, Feng and Chu (2013) and Knösel et al. (2013) studied the effectiveness of Icon infiltration resin on WSLs and proved that such noninvasive technique was capable of masking WSLs and that the obtained results remained stable after 12-m.

Regarding color change, it is estimated that the Icon resin infiltration technique could be used to reverse the alterations brought about by the WSLs' action on the demineralized enamel surface. This could have led to a negligible long-term color change assessment of the WSLs. Nonetheless, using direct visualization to ascertain the occurrence of WSLs was one of the present study's shortcomings. However, by using alternative techniques, such as the Diagnodent device, which is based on the quantitative light-induced fluorescence principle and can detect WSLs before they become noticeable to the unaided eye, the sensitivity in diagnosing WSLs might have been increased (Burnheimer et al. 2022). Additionally, as a result of the Icon resin infiltration technique's noteworthy success in enhancing the WSLs' aesthetics in the literature, (Abdullah

and John 2016; Cazzolla et al. 2018; Knösel et al. 2019; Makkar and Gupta 2015) no control group was employed for this clinical study; however, fluoride varnishes or other remineralizing products, regardless of their insignificant effect on the color masking ability of the WSLs, should have been used as a comparator in the current study for more consistent results. Consequently, the time at which the immediate color assessment reading was done, either immediately after Icon application or after a couple of weeks, could also present another point of investigation that should be taken into consideration in further clinical studies. Nevertheless, the fact that the patients were treated by different operators might demonstrate a presence of bias in the obtained results; however, consistent oral health measures and patient arrangements and appointments were alike.

Conclusions

It is possible to draw the following conclusions, given the constraints of this clinical study: low-viscosity Icon resin injection has successfully enhanced the WSLs' aesthetics. Moreover, the immediate Icon resin infiltration of the WSLs can be the first line of treatment for the active lesions in patients with low remineralization anticipation. Low-viscosity Icon resin infiltration has the ability for immediate diffusion into the WSLs giving an immediate improvement in the esthetic outcome of the WSLs. However, its long-term outcomes might not be consistent for the color change of the WSLs.

It is recommended to carry out additional clinical research to examine the enduring impact of Icon resin insertion on the anticipated color shift of various kinds of WSLs. Using a quantitative caries assessment method such as Diagnodent device as a conjunctive approach to the regular visual caries detection method for proper diagnosis and early detection of the initial caries as well as WSLs before evident cavitation is developed, would be beneficial and more clinically relative for more consistent outcomes. Moreover, it is highly required to identify the uniformity and reliability of employing the spectrophotometric tools prior to their regular use in the ordinary dental practice (Moharam et al. 2022).

Abbreviations

WSLs	White spot enamel lesions
ICDAS	International caries detection and assessment system
CPP-ACP	Casien phosphopeptide–amorphous calcium phosphate
MREC	Medical research ethical committee
NRC	National Research Centre
SD	Standard deviation
dz	Effect size
ICC	Inter-class correlation coefficient
Sig	Significant

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Author contributions

MHZ and LMM designed the study. AA, TMH, RSS, SNH, ZMZ, and LMM collected data. MHZ, TMH, RSS, DYZ, and AA analyzed data. MHZ, LMM, and DYZ checked the data and the results. MHZ, AA, RSS, TMH, and LMM interpreted data and wrote the report. MHZ, RSS, LMM, and TMH revised the report from preliminary draft to submission. LMM modified the language, revised, and modified the final manuscript. MHZ and DYZ supervised the study. All authors have read and approved the manuscript.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

This study received ethical approval from the Medical Research Ethical Committee (MREC) of National Research Centre (NRC); Cairo, Egypt (Reference number: 20157). All methods were performed in accordance with the Declaration of Helsinki. The legal guardian of each participant signed a written informed consent form. Moreover, a verbal informed consent was taken from each participant as well upon approval from Medical Research Ethical Committee (MREC) of National Research Centre (NRC).

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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