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Effects of at-home bleaching and resin infiltration treatments on the aesthetic and psychological status of patients with dental fluorosis: A prospective study

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ABSTRACT

Objective: This study aims to evaluate the effect of the combination approach of at-home bleaching (HB) and resin infiltration (RI) techniques on different severity degrees of dental fluorosis (DF) and further analyze the psychological changes caused by HB and RI in patients.

Method: Twenty-two patients (4 males, 18 females, 27.8 ± 1.6 yrs) with 186 fluorotic teeth were included in this study and classified into mild (N = 56), moderate (N = 100) and severe (N = 30) DF groups according to the Dean's index. The treatment effects on patients with DF were assessed by questionnaires including the changes in patients' subjective evaluation of their teeth and psychological status before and after treatments. Standardized digital photographs were taken at each time point of the treatment process, including baseline (T1), after bleaching (T2), immediately after RI treatment (T3) and more than six months after RI treatment (T4). The color alterations (ΔE) between the fluorotic (F2) and the surrounding relatively sound areas (F1) were analyzed.

Results: Bad tooth appearance caused 13.64% of patients often depressed, frustrated, or disappointed, whereas 72.72% occasionally had these feelings. After treatment, the satisfaction of DF patients regarding tooth appearance increased from 0% (satisfied) to 58.82% (satisfied) and 23.53% (very satisfied). Moreover, these treatments improved all patients' confidence in smiling, laughing and showing their teeth. The percentage of fluorotic teeth with ΔE values more than 3.0 and 3.7 units decreased gradually from T1 stage to T3 stage in mild and moderate DF groups ($p < 0.05$), whereas the ΔE value in T3 stage was significantly lower than that of T2 stage in severe DF group ($p < 0.05$). In T4 stage, no significant difference was observed in the ΔE values between T4 and T3 stages ($p > 0.05$).

Conclusion: This study shows the obvious positive aesthetic effect of HB and RI treatment on different severity degrees of DF and the great improvements in psychological discomforts.

Clinical significance: The combination treatment of RI and low concentration HB gel improves the aesthetics of DF and may have a stable effect after 6-months follow-up, suggesting that this approach is a valuable clinical choice for dentists to treat DF.

1. Introduction

Dental fluorosis (DF) is a developmental disorder of the enamel caused by excessive fluoride absorption on ameloblasts during enamel development. This disorder results in the hypomineralization of the enamel, such as enamel subsurface porosity, which is characterized by white opaque areas, and discolorations, which vary from light yellow to dark brown, when extrinsic stains were absorbed into the porosity [1]. One of the most common sources of fluoride ingestion by humans is from drinking water [2], and other sources include diet, beverages, salt, dietary supplements, and fluoride-containing dental products [2–4]. The severity of DF is linked to fluoride dose and the timing and duration of fluoride exposure [5]. The prevalence of DF had been reported worldwide and had been described in several endemic areas, such as

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Southern India (64.3%) [6] and Mexico City (59%) [7], and DF prevalence in the US increased from 29.7% in 2001–2002 to 61.3% in 2011–2012 [8]. Recently, a national survey in China presented that the prevalence of DF is 13.4%, and DF is observed more in the rural areas, which have more fluoride pollution, than in the urban areas [9]. In China, the top two most seriously affected places are the Guizhou province (51.6%) and the Tianjin city (45%), wherein DF was mainly caused by coal burning and fluoride pollution in drinking water, respectively [9]. Considering the complex etiology and higher prevalence of DF in certain areas in China, more attention should be paid to the prevention and treatment of DF.

DF is not a disease that can cause obvious pain or discomfort, but it can affect the color and the structure of enamel and can lead to unsightly appearance, especially if the discoloration or pitting were in the visible regions of DF. Several studies reported that patients with DF can feel displeasure or shame [10], and even depression and stress [11], resulting in a decline in patients' self-confidence and self-esteem [12] and hidden smiles [13]. The degree of influence of DF on patients may be related to the severity degree of DF, patients' self-perception of the DF, and their psychological endurance. Overall, the unsightly appearance due to DF can have a negative effect on the patients' quality of daily life [13], psychological health [14] and social behavior. Therefore, dentists should pay more attention to this problem in clinical practice.

Several techniques have been advocated to improve the aesthetic imbalance caused by DF. Minimally invasive include removing the surface-stained areas through enamel bleaching, microabrasion, and resin infiltration (RI) techniques [15] alone or in combination, whereas invasive approaches include veneers and crowns [16]. These methods have shown varying degrees of success and are chosen depending on the severity degrees of DF, patient's selection, and the dentists' medical concept and technical level. Bleaching techniques have become popular in recent years because it is safe, inexpensive, and minimally invasive and can remove external or internal discoloration from teeth [17]. Among the available bleaching products in the market, the carbamide perioxide (CP) gel is broadly preferred for vital tooth bleaching [18,19]. RI is originally developed to prevent incipient enamel caries and has also been recommended for the disappearance of white spot lesions (WSL) [20]. RI can prevent the further progression of enamel lesions and stains after bleaching, because this treatment occludes the microporosities within the enamel by infiltration with low-viscosity light-curing resins that have been optimized for rapid penetration into the porous enamel [21]. The performance or masking efficacy of RI in hypomineralized or carious enamel has been demonstrated already, but few information is available on the systematic evaluation of the phased effect of RI on the treatment of DF.

DF is an oral disease that cannot be neglected and has obvious influence on the aesthetics of teeth. At present, studies on the application of minimally invasive treatments and the psychological effect of DF on patients are still scarce. A detailed psychological assessment of patients with DF and an effect after 6-months follow-up for new treatment methods will help to improve the evaluation of the therapeutic effect. Thus, this study was conducted with a follow-up time more than 6 months to assess the hypothesis that the combination of RI and preceding at-home bleaching (HB) could significantly improve the aesthetics of DF with different degrees of severity in a Chinese population, and a secondary aim was to assess the changes in patients' psychology during the treatment according to the questionnaires.

2. Materials and methods

2.1. Including and excluding criteria

During a period of four years, every patient who was diagnosed with mild to severe DF seeking aesthetic treatment at the Department of Endodontics, Hospital of Stomatology, Tianjin Medical University, China and meeting the eligibility criteria was included in this study. Informed consents were obtained from participants prior to their enrollment in the study. A total of 22 adult participants (4 males and 18 females; mean age = 27.8 ± 1.6 years old) with 186 fluorotic teeth (anterior teeth and premolars) were enrolled according to the inclusion and exclusion criteria. In view of the different severity degrees of DF, the patients were classified into three groups (mild, moderate, and severe) based on the Dean's Index [22]. The inclusion criteria for selecting cases were as follows: patients (1) with DF and were treated with the combination approach of HB and RI techniques; (2) who had complete data, including images taken under the same condition at each time point during the therapy process and the completed questionnaires before and after treatment; and (3) without restrictions of race, gender, region, ethnicity, and religion. The exclusion criteria were: patients (1) with contraindications according to the manufactures' instruction of the products or the technique information, (2) with orthodontic appliance, (3) with restored teeth in the treatment areas, (4) who were pregnant or lactating, (5) with a condition that could cause tooth sensitivity (noncarious cervical lesions, dentin exposure, and severe abrasion), and (6) with incomplete data (incomplete photos and treatment techniques).

2.2. Therapeutic process

The questionnaires were filled out before and after treatment, and participants' self-evaluation of color changes, psychological status, and subjective perception of teeth sensitivity were recorded. Each patient received a treatment kit, which contained a customized dental arch tray, and a bleach syringe (3 g), which contained 10% CP (Opalescence PF; Ultradent Co., South Jordan, UT, USA). Each patient was instructed to bleach 6–8 hours per night. RI therapy (ICON; DMG, Hamburg, Germany) was started two weeks after HB treatment. Patients were made to wear eyeglasses for protection during the infiltration procedure. Before RI, rubber dam was applied, and the teeth surfaces were cleaned. The treatment was carried out according to the manufacturer's instructions.

2.3. Images acquisition

Standardized photographs taken at baseline (T1), immediately after HB (T2), immediately after RI (T3), and during the follow-up visit (T4) were analyzed using the image analysis software Photoshop CS6 (Adobe; San Jose, USA). Clinical photographs were taken using a digital camera (EOS 600D; Canon, Tokyo, Japan), macrolens (Canon EF 100 mm Macro Lens; Tamron, Saitama, Japan), and flash (MT 24-EX Twin Lite; Canon) in well-lit, standardized, ambient conditions, such as the same chair position. Field illumination was maintained throughout all assessments. The camera settings used were as follows: shutter speed of 1/200, F29, ISO 200, flash white balance, and ring flashlight intensity of 1/2. The teeth were dried naturally, and the photos were taken after 20 s to minimize light reflection.

2.4. Color recording and evaluating

The measurements were performed by an examiner after the random labeling of photographs to avoid unwanted measuring bias. The surrounding relatively sound area (F1) and the fluorotic area (F2) were outlined on the screen, and the colors of the F1 and the F2 areas were measured by software photoshop CS6. The RGB (Red, Green, Blue) values of the F1 and the F2 areas were obtained from each tooth and then were transformed into the CIE L*a*b* space. The CIE L*a*b* color system, which included 3 channels describing the object's luminance (L*), the chrominance from green to red axis (a*) and blue to yellow axis (b*), was used to determine the color changes and according to this system, colors in nature were obtained through the therapeutic process of the three basic colors (red, blue, and green) in certain proportions.

The ΔE values between the F1 and the F2 areas were calculated as follows: $\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{½}$. ΔL* depicts the difference of lightness between the F2 and the F1 areas while Δa* and Δb* depicts the difference of chroma in the red-green axis and yellow-blue axis between the F2 and F1 areas respectively.

A ΔE value of 3.0 units was sometimes regarded as an indicator for mismatching colors. However, according to most studies concerning color stability, a color change was said to be clinically visible in any site when the ΔE data were higher than 3.7 units [23]. Therefore, thresholds of 3.0 and 3.7 units were established for the CIE L*a*b* ΔE. The collective ΔE data of the F1 and the F2 areas at T1, T2, T3 and T4 were assessed. The color at the F1 and the F2 areas were determined at each time point in each group.

2.5. The evaluations of white spots on teeth surfaces of DF after HB and RI

The sizes of the white spot (W) and the total labial or buccal tooth surface (S) were measured, and the W: S ratio (%) was determined two weeks after HB and immediately after RI treatment. The results were classified into three groups: completely masked, partially masked, and unchanged. The images of partially masked teeth were analyzed using the image analysis software Image-pro plus 6.0 (Media Cybernetics, Bethesda, Maryland, USA).

2.6. Statistical analysis of color change and white spots during the process

Statistical analysis was performed using the statistical program SPSS Version 20 (SPSS Inc., Chicago, IL, USA). Paired *t*-test ($p = 0.05$) was used to compare the changes in the collected ΔE values and the segregated L*, a* and b* values between the F1 and the F2 areas at time points T1 to T4. Statistical evaluation of the W: S ratio was performed using the Wilcoxon's signed rank test. All data were measured three times by an investigator at the same conditions, and the average of the measured values was taken to calculate the ΔE at each stage.

3. Result

A total of 22 patients with 186 fluorotic teeth were included in this study. Of the 22 patients, 18 were females and four were males, yielding an overall female to male ratio of 4.5 ($p < 0.05$). The patients' ages ranged from 16 years old to 47 years old (mean age, 27.8 years). Twenty patients reported information related to their level of education; 19 patients (95%) had undergraduate degrees or above, and one was a high school student. Dean's index revealed that teeth with moderate DF (100, 53.8%) was the most common type relative to teeth with mild (56, 30.1%) and severe DF (30, 16.1%). The average duration of HB (mean ± SD) in patients with mild, moderate, and severe DF was 6.5 ± 1.0, 7.8 ± 1.1, and 11 ± 3.0 weeks, respectively. However, no significant difference was observed among the three types of DF ($p > 0.05$). In the T4 stage, 18 patients (82%) returned, and the average follow-up time was 16 ± 11.8 months.

3.1. Patients' self-evaluation questionnaires of their teeth and psychological status

In the questionnaire before treatment, 13.64% of the patients reported that they often felt depressed, frustrated, or disappointed due to the poor color of their DF, and 72.72% felt occasionally uncomfortable. Approximately 9.09% of the patients were eager to have white teeth, 77.27% hoped to achieve tooth color close to healthy natural teeth, and 13.64% reported that they would be satisfied as long as the tooth color could be improved. In comparison with invasive therapies, such as porcelain veneer or full crown, 90.91% of patients were more likely to choose minimally invasive aesthetic treatment.

The satisfaction of patients with tooth color increased from 0% (satisfied) before treatment to 23.53% (very satisfied) and 58.82% (satisfied) after treatment. The number of patients who reported acceptable tooth color decreased from 27.27% to 17.75%. By contrast, the number of patients who were dissatisfied and reported a serious effect on their lives decreased from 77.73% to 0%. Before treatment, the range of tooth color scored by patients' subjective evaluation was from 0 to 8, in which 18.18% of the patients scored 0–2, 64.64% scored 3–5, and 18.18% scored 6–8. After treatment, the score range was changed from 6 to 10 for their teeth, including 70.59% of patients with a score of 6–8 and 29.41% of patients with a score of 9-10. Approximately 59.09% of the patients said they did not dare laugh, smile, or show their teeth before treatment, and 40.91% of the patients said that they would hesitantly laugh or show their teeth. However, 100% of the patients said that they could confidently laugh or smile and regained self-esteem after treatment. After treatment, 52.94% of the patients thought that the family bleaching method was quite comfortable, whereas 47.06% thought that family bleaching was comfortable most of the time. The patients occasionally had sensitivity, but no one felt uncomfortable.

Table 1
The numbers and percentages of fluorotic teeth with the value of ΔE > 3.0 or 3.7 units between the F1 and the F2 areas during the treatment process.

Groups(the number of the teeth)	ΔE between F1 and F2 area	T1		T2		T3	
		N	%	N	%	N	%
Mild DF(56)	> 3.0	53	95	42	75*	29	52**
	> 3.7	49	88	38	68*	26	46**
Moderate DF(100)	> 3.0	95	95	79	79*	66	66**
	> 3.7	94	94	74	74*	51	51**
Sever DF(30)	> 3.0	30	100	28	93	25	83
	> 3.7	30	100	28	93	21	70**

$\Delta E_{(F1T1\ -\ F2T1)} = [(L^*_{F1T1} - L^*_{F2T1})^2 + (a^*_{F1T1} - a^*_{F2T1})^2 + (b^*_{F1T1} - b^*_{F2T1})^2]^{1/2}$ gives the color difference between F2 and F1 area at T1 ; $\Delta E_{(F1T2\ -\ F2T2)} = [(L^*_{F1T2} - L^*_{F2T2})^2 + (a^*_{F1T2} - a^*_{F2T2})^2 + (b^*_{F1T2} - b^*_{F2T2})^2]^{1/2}$ gives the color difference between F2 and F1 after completion of the at T2 ; $\Delta E_{(F1T3\ -\ F2T3)} = [(L^*_{F1T3} - L^*_{F2T3})^2 + (a^*_{F1T3} - a^*_{F2T3})^2 + (b^*_{F1T3} - b^*_{F2T3})^2]^{1/2}$ gives the color difference between F2 and F1 at T3.
Significant difference between the two groups: *$p < 0.05$ Between T1 and T2 and **$p < 0.05$ Between T2 and T3.

3.2. Color discrepancy evaluation at each time point during treatment

Table 1 shows that the percentage of fluorotic teeth with ΔE values more than 3.0 and 3.7 units decreased from T1 to T3 in mild and moderate DF ($p < 0.05$), respectively. In severe DF, the percentage of teeth with ΔE greater than 3.7 had no significant change between the T1 and T2 stages ($p > 0.05$), but the ΔE value in the T3 stage was significantly different from that in the T2 stage ($p < 0.05$).

3.3. Color development during therapy: collective ΔE and segregated ΔE data of (L*), (a*), (b*)

Table 2 shows the mean values of CIE ΔE and CIE L*, a*, and b* of T1, T2, and T3. The comparison results of the data of T2 with T1 and T3 with T2 demonstrated that the ΔE values of the mild, moderate, and severe DF groups significantly decreased ($p < 0.05$).

CIE L* data: At T2, a significant reduction in L* values was observed in F1 and F2 compared with T1 in the moderate and severe DF groups ($p < 0.05$). The comparison result of the L* values of T3 with T2 indicated a significant decrease in F1 of the moderate and severe DF groups and F2 of the mild and moderate DF groups ($p < 0.05$).

CIE a* data: A significant reduction in the values of a* was noted in F1 and F2 of the moderate and severe DF groups at T2 compared with that at T1 ($p < 0.05$). The comparison result of the a* values of T3 with T2 demonstrated a significant increase in F1 of the mild and severe DF groups and F1 and F2 of the moderate DF group ($p < 0.05$).

CIE b* data: A significant decrease in b* values at T2 was observed

Table 2
Mean values (SD) of L*, a*, b* in different severity degrees of DF at each time point during the treatment process.

Group(the number of teeth)	Color Parameter	T1	T2	T3
Mild DF(56)				
F1	L*	74.07 ± 8.58	74.71 ± 4.73	74.68 ± 6.56
	a*	3.5 ± 3.13	3.07 ± 2.52	2.41 ± 1.97***
	b*	12.88 ± 4.74	6.64 ± 4.06**	8.25 ± 3.89***
F2	L*	78.36 ± 9.18	77.52 ± 5.03	75.52 ± 6.25***
	a*	1.57 ± 2.80	2.14 ± 2.61	2.41 ± 2.31
	b*	7.36 ± 7.27	3.57 ± 3.20**	6.70 ± 3.80***
Moderate DF(100)				
F1	L*	71.5 ± 7.02	77.63 ± 6.29**	75.31 ± 8.20***
	a*	4.52 ± 3.15	0.61 ± 3.17**	3.56 ± 7.95***
	b*	10.86 ± 6.67	4.63 ± 5.69**	11.63 ± 4.99***
F2	L*	62.62 ± 11.47	77.76 ± 6.46**	75.55 ± 4.14***
	a*	10.36 ± 8.81	0.06 ± 2.86**	2.31 ± 2.57***
	b*	24.11 ± 14.09	5.07 ± 8.35**	11.11 ± 4.77***
Severe DF(30)				
F1	L*	68.73 ± 9.18	81.53 ± 7.53**	72.03 ± 6.98***
	a*	6.17 ± 3.05	0.63 ± 2.28**	2.57 ± 1.91***
	b*	14.97 ± 5.81	5.47 ± 3.59**	13.67 ± 4.05***
F2	L*	52.13 ± 13.75	70.23 ± 14.76**	71 ± 6.60
	a*	16.5 ± 7.11	2.7 ± 2.22**	3.03 ± 2.97
	b*	32.7 ± 10.74	15.53 ± 8.70**	16.7 ± 5.95

The L* refers to the lightness of Munsell system, and the a* and b* presents a color change on the axis from red to green direction("a* > 0″ = red, "a* < 0″ = green) and yellow or blue direction ("b* > 0″ = yellow, "b* < 0″ = blue) respectively.
Significant difference between the two groups: **p < 0.05 between T1 and T2 and ***p < 0.05 between T2 and T3.

in F1 and F2 for all DF groups ($p < 0.05$) compared with that at T1. At T3, F1 and F2 of the mild and moderate DF groups and F1 of the severe DF group revealed higher b* values than those at T2 ($p < 0.05$). No change was discovered in F2 of severe DF ($p > 0.05$).

3.4. Masking effect of resin infiltration on white spots

Fifty-six teeth had obvious white spots after bleaching and treatment with RI. The white spots of 31 (55%) teeth were completely covered, and no more white spots were found. By contrast, the white spots of 25 (45%) teeth were partially covered. The percentage of the white spot area on the whole labial or buccal tooth surface decreased from 42.0% before treatment to 3.7% after treatment ($p < 0.01$).

Fig. 1 exhibits the trends of the mean values of ΔE, ΔL*, Δa*, and Δb* at the T1, T2, T3, and T4 stages. The mean value of ΔE was lower at the T3 stage than those at the T2 and T1 stages ($p < 0.05$). However, no significant differences were found between the T3 and T4 stages ($p > 0.05$). The mean values of ΔL*, Δa*, and Δb* at the T2 stage were evidently lower than that of the T1 stage ($p < 0.05$).

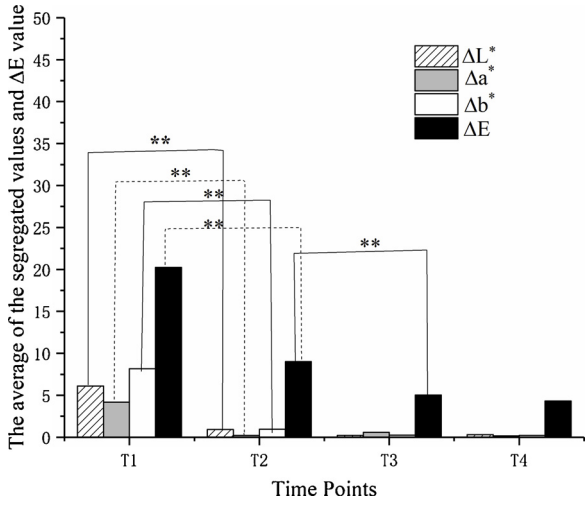

Fig. 1. The segregated (ΔL*, Δa*, Δb*, ΔE) values were calculated at each time point from T1 to T4 to analyze the color matching trend between F1 and F2 areas during the whole process. ΔL*, Δa*, and Δb*depicts the difference of lightness, chromacity in the red-green axis, and chromacity in the yellow-blue axis between F2 and F1 areas respectively.

4. Disscussion

A total of 22 clinical cases and 186 fluorotic teeth with different degrees of severity were included in this study. The questionnaires on patients' feelings and evaluation of treatment and the effects of HB and RI clinical treatment on DF were carried out in Chinese patients. In recent years, only two previous clinical studies performed a similar treatment of DF, which included bleaching and RI. The questionnaire survey on the psychological changes caused by DF and treatment, inclusions of DF with pitted or defected enamel surface in the present study were the main differences with the previous studies [24,25]. The follow-up period in the present study was from six months to four years after RI treatment, and 41.8% fluorotic teeth had been followed up for more than one year, which was longer than that of previous studies [26,27]. Compared with these previous studies, the current study had longer avarage follow-up time, which could further contribute to provide a reference for the masking effect and color stability of RI in treating DF.

In this study, the patients included were still relatively young. However, the frequency of dental whitening consultation for the elderly in outpatient clinics was increasing, and they were more sensitive on treatment fee and comfort. The number of women included in this study were significantly more than men, indicating a significantly higher awareness of females about aesthetic appearance than males, and our findings were consistent with those of previous studies [24,25]. Moreover, the study found that most of the patients had a higher education background, which was not reported in previous studies, and suggested a more active pursuit of beautiful appearance and confident smile. Most of the patients had more demand for noninvasive aesthetic treatment, which indicated patients' better awareness of preserving teeth.

With the rapid development of China's economic and social levels and the increase in interpersonal communication in the society, the effect of tooth diseases on the patients' psychological and mental health has attracted the attention of researchers and dentists. The present study also confirmed that DF can evidently affect the patients' physical and mental health in many ways. For example, DF can have an obvious

negative effect on the patients' self-confidence and can cause the patient to be in a bad mood with depression, frustration, and interpersonal communication barriers. The questionnaire after treatment suggested that the therapy methods applied in this study greatly improved the patients' subjective satisfaction, scoring of teeth color, self-esteem, optimism, and willingness to communicate with others. Until now, previous studies have not been conducted to evaluate the effect of treatment on the psychological health of patients with DF, and the follow-up of this study suggested that patients were still satisfied with the aesthetic results even after three or four years. Therefore, the present questionnaire survey provided a reliable supporting evidence for the combined methods applied on the treatment of DF.

In the present study, less than half of the patients reported that the HB with a 10% CP gel occasionally caused mild dentine sensitivity but did not influence the tooth bleaching progress. This result was similar with several clinical studies, which validated the effectiveness and safety of HB modality [28,29]. A similar result can be achieved by different bleaching gels with inconsistent concentration. Bleaching gels with a higher concentration may result in a faster rate of tooth bleaching [30,31] and can be associated with more postprocedure dentine sensitivities in the early stages of treatment [32]. Overall, the use of different concentrations of bleaching products depends mainly on the experience of the clinician, the difficulty of treatment, and the patients' treatment time requirements.

The present study analyzed patients' subjective evaluation and objectively assessed the color improvement after treatment with an image analysis method, which had been applied in a previous study [25]. Using software analysis, the RGB values can be transformed into the CIE L*a*b* color space, which is an international system used as standard for color measurements in previous studies [33,34,35]. The ΔE value was evaluated with the measured CIE L*a*b* values at each stage, and the color discrepancy between the two parts was quantified. The threshold of 3.0 and 3.7 units were also generally used to evaluate the color difference on the teeth in some clinical studies [33,35]. The present study suggested that whether it was evaluated by the threshold of 3.0 or 3.7 units in mild and moderate DF, the overall color coordination of teeth was continuously improved by HB and RI treatment, showing that the combination of the two methods greatly improved the clinical effect, which was also in agreement with the clinical experience. RI treatment after HB masked some areas with slight difference in color and made the overall color more harmonious, but no similar previous studies had been reported.

Further detailed studies suggested that a significant change in the b* value can be the main reason for the change in ΔE data in the mild DF group after HB. In the moderate and severe DF groups, the change in ΔE value may be due to the mixed action of L*, a*, and b* values. A possible reason was that mild DF was usually characterized by white opaque lesions rather than staining, and the overall color of the tooth surface was closer to each other after HB. The decrease in b* value represented a color change from yellow to blue and indicated that the natural yellowness of Chinese teeth turned to a more neutral color (white or gray). The moderate DF group was characterized by varying degrees of staining. Meanwhile, the severe DF group was characterized by defects on the enamel surface of tooth, and after HB, the total a*, b*, and L* values significantly changed, which showed that HB can remove the staining on the surface of teeth, make the color more neutral, enhance the chalkiness on the surface of teeth, and improve the overall brightness of teeth.

Only one previous study of HB for DF included an analysis of segregated L*, a*, and b* values, but the results were difficult to compare with those of the current study, because the mild and moderate DF in the previous study were not discussed separately. However, two studies indicated that the brightness and saturation of DF significantly changed after HB, suggesting that HB can significantly improve the brightness and decrease the saturation of DF. In severe DF, an obvious change in L*, a*, and b* values was observed in the F1 area after RI, but no significant change in these values was found in the F2 area. Because most severe DF showed pitting or defects on the surfaces of teeth due to extrinsic mechanical breakdown [33,36], the color of these areas was similar to the dentine and was usually more obvious than the surrounding healthy enamel after bleaching or even after RI. Therefore, composite resin should sometimes be used to fill the pitted or defected areas and to reduce the overall color difference of teeth. The largest color change in the whole treatment procedure was observed in the T2 stage, as presented in the data shown in Fig. 1, suggesting that bleaching had a very obvious effect on improving the dental aesthetics in treatment of DF and may be regarded as a basic treatment of DF.

HB can significantly improve the color of DF, and RI can restore the porous structure of enamel surface and improve the intensity and luster of white spot after decolorization of DF. The follow up further confirmed the stability of the two methods combined in aesthetic treatment of DF, but the long-term effect still needs further observation. Although these two methods can effectively improve DF, the complexity of treatment procedures, longer time, and uncertainty in the treatment of complex cases still pose challenges for future treatment, and more effective methods still need to be explored.

5. Conclusions

In this study, the combination of HB and RI significantly improved the management of DF at different degrees of severity and the psychological status of patients. The efficacy after 6-months follow-up demonstrated in this study indicated that the color of RI was stable at the oral condition, because RI provided additional potential to successfully delay and prevent color resorption.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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