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Original Article

Therapeutic effect of permeable resin and composite resin filling combined with self-etching adhesive in the treatment of dental caries in children

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Abstract: Objective: To evaluate the clinical effect of permeable resin filling compared with composite resin filling compared with a self-etching adhesive in the treatment of dental caries in children. Methods: A retrospective analysis was conducted on the clinical data of 118 children with dental caries treated at Shenzhen Second People's Hospital from April 2021 to April 2024. According to the treatment plans, patients were divided into two groups: the control group (n = 59), treated with composite resin filling and a self-etching adhesive, and the observation group (n = 59), treated with permeable resin filling. The overall clinical efficacy and adverse reactions were assessed at 3, 6 and 12 months after treatment. In addition, inflammatory markers [Tumor necrosis factor-α (TNF-α), interleukin-6 (IL-6), interleukin-8 (IL-8)], periodontal health indicators [bleeding index (BI), plaque index (PLI), gingival index (GI), probe depth (PD)], restoration quality (marginal adaptation rate and retention rate), tooth sensitivity, treatment cooperation [visual analog scale (VAS) score, Tactile value, Schiff score, Houpt score, Frank1 score] and oral health-related quality of life-based on the Children's Oral Health Impact Profile (COHIP) scale were evaluated before and 3 months after treatment. Results: At 3, 6 and 12 months after treatment, the observation group showed significantly higher overall clinical efficacy compared to the control group ($P < 0.05$). Subgroup analysis revealed that among patients with superficial caries, the observation group achieved a significantly higher response rate ($P < 0.05$). After treatment, levels of TNF-α, IL-6, IL-8, BI, PLI, GI, PD, VAS, Schiff score, Houpt score, Frank1 score, and COHIP score decreased in both groups, while tactile value increased. Moreover, the observation group exhibited greater improvements across all inflammatory, periodontal, restorative, tooth sensory, behavioral and quality of life metrics compared to the control group ($P < 0.05$). The incidence of adverse reactions was 5.08% in the observation group and 13.56% in the control group, with no statistically significant difference ($P > 0.05$). Conclusion: Permeable resin filling demonstrates superior permeability, enhanced caries repair outcomes, and favorable safety in the treatment of pediatric dental caries, making it a clinically valuable therapeutic option.

Keywords: Permeable resin, composite resin, self-etching adhesive, dental caries

Introduction

Dental caries is among the most prevalent chronic oral diseases in children, with a high incidence and progressive nature that can significantly compromise oral health, physical development, and quality of life [1-3]. Globally, approximately 60%-90% of school-aged children are affected by dental caries, with a particularly high prevalence in developing countries. In China, the incidence of dental caries in children has been rising in recent years, largely due to increasingly refined dietary habits and insufficient awareness of oral hygiene practices [4, 5]. If not properly treated, dental caries may result in tooth loss, subsequently impairing masticatory function, disrupting normal maxillofacial development, and contributing to psychosocial difficulties and social challenges in affected children [6, 7]. Therefore, it is crucial to select minimally invasive, efficient caries restorative techniques that ensure a high degree of cooperation from pediatric patients. Traditional caries treatment primarily involves the mechanical removal of decayed tissue followed by restoration using composite resin. This approach offers several advantages, including high mechanical strength and favorable aesthetic outcomes. However, it often requires acid-etching techniques that can exacerbate

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microstructural damage to dental tissues and demand a high degree of patient compliance - posing challenges in pediatric populations [8, 9]. Additionally, composite resins are susceptible to marginal microleakage, increasing the risk of secondary caries. Although the introduction of self-etch adhesives has simplified clinical procedures, their ability to infiltrate deeply demineralized dentin remains controversial. In recent years, resin infiltration (e.g., ICON, DMG), a minimally invasive technique, has gained increasing attention for the management of early to moderate carious lesions. This approach involves the use of low-viscosity resin that penetrates demineralized enamel or dentin, thereby arresting caries progression and reinforcing affected tissues - without the need for mechanical cavity preparation. As such, resin infiltration is particularly effective for pediatric dental caries due to its minimally invasive nature [10]. However, most existing studies have focused on adult patients or caries in permanent dentition. Comparative research on the clinical efficacy of resin infiltration versus composite resin combined with self-etch adhesives in the treatment of pediatric dental caries remains limited and inconclusive. Therefore, this study aimed to compare the clinical efficacy of these two treatment methods in children, with the goal of informing optimized clinical treatment strategies in pediatric dentistry.

Materials and methods

Study population

This retrospective cohort study included pediatric patients diagnosed with dental caries and treated at the Department of Stomatology, Shenzhen Second People's Hospital, between April 2021 and April 2024. A total of 59 children who underwent treatment with resin infiltration were enrolled as the observation. An additional 59 children who received composite resin fillings combined with a self-etching adhesive during the same period were selected as the control group. The two groups were matched 1:1 by sex to minimize confounding bias.

Inclusion criteria were as follows: (1) Age between 3 and 12 years; (2) Diagnosis of caries in primary teeth or immature permanent teeth; (3) Presence of Class I or Class II carious lesions, based on Black's classification.

Exclusion criteria included: (1) Presence of severe systemic diseases; (2) Diagnosis of pulpitis or periapical periodontitis; (3) Extensive loss of tooth structure requiring full crown restoration; (4) Known allergy to any dental treatment materials; (5) Incomplete or missing clinical data. The study was approved by the Ethics Committee of Shenzhen Second People's Hospital (Approval No. 20240601052-FS01).

Treatment methods

In the control group, treatment was performed using composite resin (3M ESPE Filtek™ Z350 XT) in combination with a self-etching adhesive (3M ESPE Scotchbond™ Universal). After complete removal of the carious tissue, selective enamel etching was carried out using 37% phosphoric acid gel (Ultra-Etch™) for 30 seconds, after which the area was thoroughly rinsed and air-dried. The self-etch adhesive was then applied and light-cured for 20 seconds. Composite resin was subsequently placed in incremental layers, with each layer cured under light for 40 seconds. In the observation group, resin infiltration (Icon, DMG) was used. After minimally invasive removal of the carious lesion, 15% hydrochloric acid gel (Icon-Etch) was applied for 2 minutes, followed by rinsing and drying. Ethanol was then applied for 30 seconds to facilitate dehydration. The infiltrating resin was applied for 3 minutes, the excess surface resin was removed, and the treated surface was light-cured for 40 seconds (**Figure 1**).

Observation indicators

Clinical efficacy assessment: Clinical outcomes were evaluated 3, 6, and 12 months after treatment, following the criteria outlined in the Guidelines for the Prevention and Treatment of Dental Caries in China (2016 Edition) [11]: Markedly effective: Complete resolution of clinical symptoms, thorough removal of carious tissue, stable retention of the filling material, and absence of secondary caries. Effective: Improvement in clinical symptoms, no detachment of the filling material, and no secondary caries. Ineffective: Failure to meet the criteria for either "markedly effective" or "effective".

Inflammatory marker assessment: Gingival crevicular fluid samples were collected before treatment and at 3 months post-treatment.

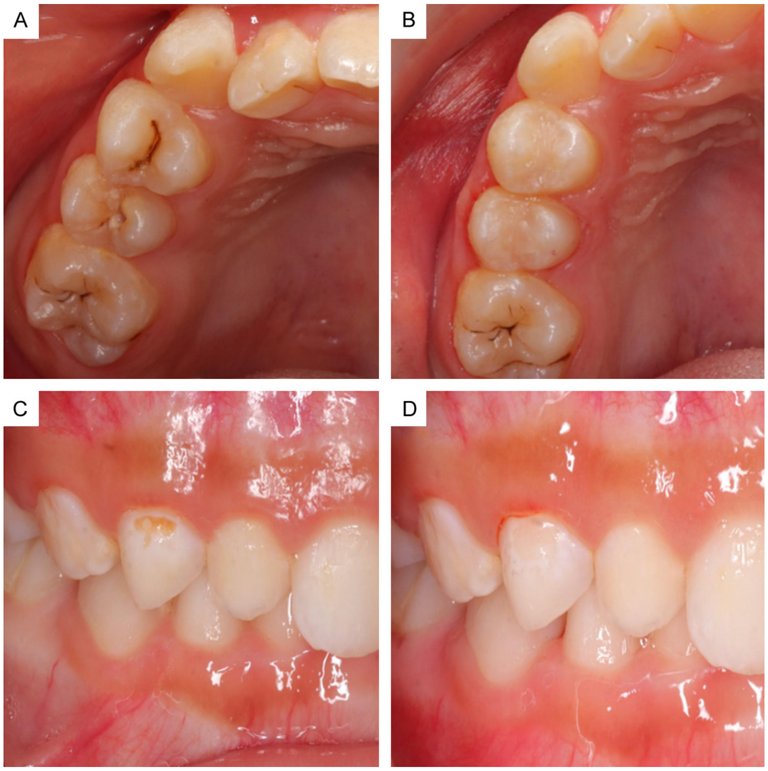

Figure 1. Oral treatment status. A. Pre-treatment condition of the control group; B. Post-treatment condition of the control group; C. Pre-treatment condition of the observation group; D. Post-treatment condition of the observation group.

Levels of tumor necrosis factor-α (TNF-α), interleukin-6 (IL-6), and interleukin-8 (IL-8) were quantified using enzyme-linked immunosorbent assay (ELISA).

Comparison of periodontal health indicators before and after treatment

At baseline and 3 months post-treatment, periodontal health indicators were assessed and compared between the two groups, including the bleeding index (BI), plaque index (PLI), gingival index (GI), and probing depth (PD).

BI assessment: A periodontal probe was inserted into the gingival sulcus to evaluate bleeding. Scoring was defined as follows: 0 = healthy gingiva, no bleeding; 1 = healthy gingiva, slight bleeding; 2 = bleeding present; 3 = mild gingival swelling with bleeding; 4 = obvious gingival swelling with bleeding.

PLI assessment: Dental plaque was disclosed using a staining agent, and the extent of plaque accumulation was recorded according to the following criteria: 0 = no visible plaque; 1 = slight plaque accumulation; 2 = moderate plaque accumulation; 3 = heavy plaque accumulation.

GI assessment: Gingival status was evaluated using the Silness gingival index, which considers gingival color, texture, and bleeding. Severity was scored as 1 = mild; 2 = moderate; 3 = severe.

PD assessment: A UNC-15 periodontal probe was gently inserted into the gingival sulcus until slight resistance was encountered. The distance from the gingival margin to the bottom of the sulcus was recorded as the probing depth (PD).

Comparison of restoration outcomes: Restorative outcomes were evaluated and compared between the two groups at baseline and 3 months after treatment, focusing on marginal adaptation and tooth retention grading.

Tooth retention grading: Grade I: Smooth and continuous tooth contour with good integration of the restoration. Grade II: Noticeable surface irregularities or roughness of the restoration. Grade III: Partial or complete loss or fracture of the filling material.

Marginal adaptation grading: Grade I: The periodontal probe cannot penetrate the interface between the restoration and the tooth structure. Grade II: The periodontal probe can penetrate the restoration margin. Grade III: Complete loss of the filling material.

Assessment of tooth sensitivity and treatment compliance: To evaluate treatment-related discomfort and behavioral response, the VAS score, Tactile threshold, Schiff score, Houpt score, and Frankl score were recorded and compared between the two groups before treatment and at 3 months post-treatment.

VAS score: Used to assess the intensity of dentin hypersensitivity-related pain in children, ranging from 0 to 10. Higher scores indicate more severe pain.

Table 1. Comparison of baseline characteristics between the two groups

Index	Treatment group (n = 59)	Control group (n = 59)	t/χ^2	*P*
Sex				
Man	33 (55.93)	37 (62.71)	0.562	0.454
Female	26 (44.07)	22 (37.29)		
Age (years)	7.84±1.17	7.61±1.35	0.989	0.325
Number of affected teeth	2.18±0.34	2.31±0.41	1.875	0.063
Severity of dental caries				
Shallow caries	31 (52.54)	34 (57.63)	0.308	0.579
Medium caries	28 (47.46)	25 (42.37)		

Table 2. Comparison of clinical efficacy between the two groups at different time points

Group	3 months after operation	6 months after operation	12 months after operation
Treatment group (n = 59)	55 (93.22)	52 (88.14)	50 (84.75)
Control group (n = 59)	44 (74.58)	41 (69.49)	39 (66.10)
χ^2	5.631	6.141	5.532
P	0.018	0.013	0.019

Tactile threshold score: Measured using a pressure-sensitive probe. A higher score denotes a higher threshold to tactile stimuli, indicating reduced tooth sensitivity.

Schiff cold air sensitivity test: Evaluates sensitivity to cold air stimulation on a scale of 0-3. A higher score reflects greater sensitivity.

Houpt behavior rating scale: Assesses the child's behavioral tolerance during dental procedures on a scale from 1 to 6, with higher scores indicating better tolerance and cooperation.

Frankl behavior rating scale: Measures the degree of patient cooperation during treatment, scored from 0 to 4. Higher scores represent greater cooperation.

Quality of life assessment: The Chinese Version of the Children's Oral Health Impact Profile-Short Form (COHIP-SF19) was used to evaluate changes in oral health-related quality of life before treatment and at 3 months post-treatment. Higher scores indicate a better quality of life.

Adverse events monitoring: Adverse events occurring during the treatment and follow-up periods, including postoperative dentin sensitivity, restoration detachment, secondary caries, and gingival irritation, were recorded.

Statistical analysis

Data were analyzed using SPSS version 26.0. Categorical variables were expressed as n (%) and compared using the chi-square (χ^2) test. Ordinal data were analyzed using the rank-sum test. Continuous variables with normal distribution were expressed as mean ($\bar{x}$±s) and compared using the t-test. A *p*-value < 0.05 was considered significant.

Results

Baseline characteristics of the two groups

There were no significant differences in baseline characteristics between the two groups (P > 0.05) (**Table 1**).

Comparison of overall clinical efficacy between the two groups

At 3, 6, and 12 months post-treatment, the observation group demonstrated significantly higher total effective rates compared to the control group (P < 0.05) (**Table 2**).

Comparison of clinical efficacy based on caries severity

Among patients with superficial caries, the observation group showed a significantly higher total effective rate at all follow-up time points

Table 3. Comparison of clinical efficacy in patients with different degrees of dental caries

Group	3 months after operation		6 months after operation		12 months after operation	
	Shallow caries	Medium caries	Shallow caries	Medium caries	Shallow caries	Medium caries
Treatment group (n = 59)	30 (96.77)	25 (89.29)	29 (93.55)	23 (82.14)	29 (93.55)	21 (75.00)
Control group (n = 59)	27 (79.41)	17 (68.00)	25 (73.53)	16 (64.00)	24 (70.59)	15 (60.00)
χ^2	4.529	1.292	4.622	2.237	5.679	1.364
P	0.033	0.256	0.032	0.135	0.017	0.243

Table 4. Comparison of inflammatory marker levels between the two groups

Group	IL-6 (pg/mL)		IL-8 (pg/mL)		TNF-α (pg/mL)	
	Before treatment	After treatment	Before treatment	After treatment	Before treatment	After treatment
Treatment group (n = 59)	2.87±0.44	1.15±0.27*	1.99±0.24	1.02±0.18*	4.95±0.81	2.38±0.39*
Control group (n = 59)	2.69±0.76	1.79±0.32*	2.02±0.35	1.53±0.20*	5.14±0.74	3.07±0.42*
t	1.574	11.741	0.543	14.559	1.330	9.247
P	0.119	< 0.001	0.588	< 0.001	0.186	< 0.001

Note: Compared to before treatment levels within the same group, *P < 0.05. IL-6, Interleukin 6; IL-8, Interleukin 8; TNF-α, Tumor necrosis factor - α.

(3, 6, and 12 months) than the control group (P < 0.05) (**Table 3**).

Comparison of inflammatory marker levels between the two groups

After treatment, levels of inflammatory markers decreased in both groups, with significantly lower levels observed in the observation group (P < 0.05) (**Table 4**).

Comparison of periodontal health indicators between the two groups

Post-treatment measurements indicated significant reductions in BI, PLI, GI, and PD in both groups. The observation group showed significantly greater improvements across all periodontal indicators (P < 0.05) (**Table 5**).

Comparison of restoration outcomes between the two groups

Compared to the control group, the observation group demonstrated significantly better marginal adaptation and tooth retention grades (P < 0.05) (**Table 6**).

Comparison of sensitivity and treatment compliance between the two groups

After treatment, VAS, Schiff, Houpt, and Frankl scores decreased, while Tactile scores increased in both groups. The observation group showed significantly greater improvements across all these indicators compared to the control group (P < 0.05) (**Table 7**).

Comparison of quality of life scores between the two groups

Both groups demonstrated reductions in scores across all dimensions of the quality of life scores post-treatment, with the observation group showing significantly greater improvement (P < 0.05) (**Table 8**).

Comparison of adverse event incidence

The total incidence of adverse events was 5.08% in the observation group, including one case of gingivitis and 2 cases of filling loosening. In the control group, the incidence was 13.56%, including 2 cases of gingivitis, 1 case of tooth fracture, 2 cases of filling loosening, and 2 cases of caries recurrence. The difference between the two groups was not significant (χ^2 = 2.506, P = 0.113).

Discussion

Dental caries in children is a highly prevalent oral disease worldwide and remains a central focus of clinical research aimed at optimizing treatment protocols [12]. Traditional composite resin restorations, which rely on mechanical

Table 5. Comparison of periodontal health indicators between the two groups

Group	BI		PLI		GI		PD (mm)	
	Before treatment	After treatment	Before treatment	After treatment	Before treatment	After treatment	Before treatment	After treatment
Treatment group (n = 59)	3.07±0.44	0.97±0.22*	2.39±0.29	0.89±0.17*	1.79±0.33	0.81±0.16*	3.04±0.45	1.46±0.39*
Control group (n = 59)	2.96±0.49	1.45±0.31*	2.46±0.41	1.21±0.24*	1.92±0.45	1.17±0.13*	3.09±0.56	1.98±0.31*
t	1.238	9.699	1.071	8.357	1.789	13.413	0.535	8.017
P	0.202	< 0.001	0.287	< 0.001	0.076	< 0.001	0.594	< 0.001

Note: Compared to before treatment values within the same group, *P < 0.05. BI, Bleeding index; PLI, Plaque index; GI, Gingival index; PD, Probe depth.

Table 6. Comparison of the repair effects between the two groups

Group	Edge fit grade			Tooth retention grade		
	I	II	III	I	II	III
Treatment group (n = 59)	52 (88.14)	5 (8.47)	2 (3.39)	51 (86.44)	5 (8.47)	3 (5.08)
Control group (n = 159)	41 (69.49)	12 (20.34)	6 (10.17)	38 (64.41)	13 (22.03)	8 (13.56)
U	2.471			2.742		
P	0.013			0.006		

Table 7. Comparison of sensitivity and cooperation between the two groups

Group	VAS		Tactile		Schiff		Houpt		Frank1	
	Before treatment	After treatment	Before treatment	After treatment	Before treatment	After treatment	Before treatment	After treatment	Before treatment	After treatment
Treatment group (n = 59)	7.03±1.24	3.52±0.91*	29.46±7.73	45.91±8.42*	2.11±0.54	1.07±0.15*	5.09±0.38	4.56±0.41*	3.39±0.31	3.01±0.54*
Control group (n = 59)	6.77±1.39	4.13±1.02*	28.83±8.12	40.16±7.89*	2.03±0.51	1.53±0.22*	5.02±0.44	4.24±0.88*	3.53±0.49	2.46±0.47*
t	1.072	3.428	0.432	3.828	0.827	13.270	0.925	2.532	1.855	5.901
P	0.286	< 0.001	0.667	< 0.001	0.410	< 0.001	0.357	0.013	0.067	< 0.001

Note: Compared to before treatment values within the same group, *P < 0.05. VAS, visual analogue scale.

Table 8. Comparison of quality of life scores between the two groups

Group	Oral symptom score		Oral function limitation score		Social-emotional health score		School environmental impact score		Self-evaluation score	
	Before treatment	After treatment	Before treatment	After treatment	Before treatment	After treatment	Before treatment	After treatment	Before treatment	After treatment
Treatment group (n = 59)	30.78±4.45	8.13±2.24*	18.29±3.96	4.24±1.19*	18.89±3.42	14.20±2.42*	12.33±1.54	3.11±0.82*	17.24±2.85	7.88±2.16*
Control group (n = 59)	31.05±5.41	10.29±3.18*	17.93±4.21	6.32±1.53*	19.11±4.56	15.78±2.71*	12.57±1.69	4.20±0.73*	17.09±4.12	9.74±2.24*
t	0.296	4.265	0.478	8.243	0.296	3.340	0.806	7.626	0.230	4.591
P	0.768	< 0.001	0.633	< 0.001	0.767	0.001	0.422	< 0.001	0.819	< 0.001

Note: Compared to before treatment scores within the same group, *P < 0.05.

retention and chemical bonding, can effectively restore tooth morphology in the short term but are associated with challenges such as marginal microleakage, increased risk of secondary caries, and technique sensitivity [13, 14]. These issues are particularly pronounced in younger children, where acid etching-induced discomfort and prolonged treatment duration often compromise patient cooperation. Since its introduction to pediatric dentistry in 2010, resin infiltration technology has embodied the concept of "minimally invasive sealing" by physically occluding demineralized tissue via penetration of low-viscosity resin, theoretically overcoming the limitations of conventional treatments [15]. However, further clinical evidence is required to substantiate its long-term efficacy, suitability for pediatric behavioral management, and its impact on patient's quality of life. This study integrates multidimensional clinical data comparing both treatment approaches, providing new evidence to inform clinical decision-making in the management of pediatric caries.

The results of this study showed that one year after treatment, the overall effective rate in the control group was 66.10%, differing from the findings reported by Maru VP et al. [16]. This discrepancy may be attributed to variations in factors such as race, age, and severity of dental caries. Notably, the total effective rate, as well as the effective rate in children with superficial caries, was consistently higher in the observation group than in the control group at 3, 6, and 12 months post-treatment, indicating that osmotic resin treatment yields better clinical outcomes for children with superficial caries. Additionally, the observation group demonstrated superior restorative outcomes, reflected by higher rates of marginal adaptation and tooth retention. This can be explained by the low viscosity of the resin infiltrant, which enables penetration into the microporous structure of demineralized enamel, thereby forming a physical barrier that effectively blocks bacterial metabolite diffusion, reduces the risk of secondary caries, and enhances therapeutic efficacy [15]. In contrast, composite resin restorations used in the control group rely on mechanical retention and chemical bonding, making them more susceptible to marginal microleakage, which facilitates plaque accumulation at restoration margins and worsens long-term durability. Furthermore, the acidic environment produced by self-etch adhesive in composite resin treatments may cause sustained irritation at the dentin-resin interface, leading to a gradual decline in bonding strength over time. The observed decrease in the total effective rate in the control group over time further supports this explanation.

The study compared periodontal health-related indicators between the two groups, showing that improvements in BI, PLI, GI, and PD were significantly greater in the observation group. This superiority may be attributed to the infiltrant restorations' enhanced marginal adaptation, which reduces niches for plaque accumulation, coupled with their smoother surface texture that impedes bacterial adhesion [17, 18]. In contrast, restorations in the control group may exhibit microscopic marginal gaps, creating a "microenvironment" conducive to biofilm formation and thereby limiting treatment outcomes. Furthermore, the observation group showed better relief of dentin sensitivity and higher treatment compliance, likely because the resin infiltration technique eliminates the need for acid etching, avoiding acid-induced transient sensitivity. The simplified procedure also helps reduce children's anxiety and fear during treatment, thereby enhancing cooperation. Regarding quality of life, improvements across all assessed dimensions were more pronounced in the observation group. These findings suggest that, compared to composite resin restorations, osmotic resin treatments not only facilitate better patient cooperation but also promote positive treatment experiences, which may contribute to improved long-term oral health behaviors.

The development of dental caries in children is likely attributed to the invasion of oral microorganisms into the enamel and dentin. Upon invasion, these microorganisms stimulate macrophages and T cells to release large quantities of cytokines, which promote neutrophil migration to the infected tissues for microbial phagocytosis, thereby triggering an inflammatory response that damages dental tissues [19-21]. Previous studies have shown that inflammatory factor levels in the gingival crevicular fluid of children with dental caries are significantly elevated and correlate closely with disease severity [22]. In this study, inflammatory marker levels decreased in both groups after treatment, with a significantly greater reduction in the observation group. These results suggest that resin infiltration treatment more effectively attenuates gingival inflammation compared to composite resin restoration. This advantage may be attributed to the acid-free nature of the osmotic resin procedure, which minimizes direct chemical irritation to the dental pulp. In addition, the resin infiltrant provides a more thorough sealing effect, reducing sustained stimulation of periodontal tissues by bacteria and their metabolic byproducts.

Although the incidence of adverse reactions did not differ significantly between the two groups, the control group experienced 2 cases of caries recurrence and 1 case of vertical tooth fracture, underscoring the need for heightened clinical vigilance regarding complications following composite resin treatment.

In summary, resin infiltration treatment for pediatric dental caries demonstrated superior clinical efficacy compared to traditional composite resin, particularly in managing superficial caries, controlling inflammation, maintaining periodontal health, and enhancing treatment compliance, while exhibiting a while exhibiting safety profile. Therefore, resin infiltration is recommended as a first-line treatment in clinical practice, especially for younger children, multi-surface caries, and patients with poor treatment cooperation. However, caution is warranted when applying resin infiltration to deep caries with pulp exposure, and careful evaluation of indications is essential.

However, the relatively small sample size in this study may have introduced selection bias despite matching multiple factors in the control group. Consequently, larger multicenter studies with extended follow-up periods are necessary to further validate these findings.

Disclosure of conflict of interest

None.

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