

Received: 2016.12.20
Accepted: 2017.02.06
Published: 2017.09.16

Evaluation of Four Different Restorative Materials for Restoration of the Periodontal Condition of Wedge-Shaped Defect: A Comparative Study

Authors' Contribution:
Study Design A
Data Collection B
Statistical Analysis C
Data Interpretation D
Manuscript Preparation E
Literature Search F
Funds Collection G

AE 1 **Jian-Yong Ruan***
B 2 **Zheng-Lin Gong***
D 2 **Rui-Zhi Zhang**
F 3 **Zhe Zhang**
C 3 **Ran Xu**
D 3 **Da-Xu Li**
C 3 **Le Ren**
AG 3 **Hong Tao**

1 Department of General Dentistry, The Affiliated Stomatological Hospital of Fujian Medical University, Fuzhou, Fujian, P.R. China
2 Department of Stomatology, Ankang Central Hospital, Ankang, Shaanxi, P.R. China
3 Department of Stomatology, The 1st Affiliated Hospital, Medical School of Xi'an Jiaotong University, Xi'an, Shaanxi, P.R. China

* These authors are regarded as co-first authors

Corresponding Author: Hong Tao, e-mail: hongtao_65ht@163.com
Source of support: Departmental sources

Background: This study aimed to conduct a clinical evaluation of four restorative materials for restoration of dental wedge-shaped defect (WSD) and their impacts on periodontal tissues.

Material/Methods: A total of 280 maxillary premolars with dental WSD were selected from 106 patients; the patient cases were divided into eight groups according to different combinations of restorative materials (flowable resin composites, Dyract compomers, glass ionomer cement (GIC), light-curing composite resin), and WSD positions (approaching gingival and subgingival positions). Gingival crevicular fluid (GCF) volume, levels of aspartate aminotransferase (AST), alkaline phosphatase (ALP), and interleukin-1 β (IL-1 β) in GCF were analyzed, while probing depth (PD), plaque index (PLI), and sulcus bleeding index (SBI) were also measured. The periodontal conditions of all patients were followed prior to restoration, as well as six months and 12 months after restoration.

Results: After six months of restoration, the overall clinical success rates of flowable resin composites, Dyract compomers, and light-curing composite resin were greater than those of GIC. GCF volume, GCF-AST, IL-1 β levels, PD, PLI, and SBI of cases restored by GIC were higher than those restored by the other three materials. After 12 months of restoration, the overall clinical success rates of flowable resin composites and Dyract compomers were greater than those of light-curing composite resin and GIC. GCF volume, GCF-AST, GCF-ALP, IL-1 β levels, PD, PLI, and SBI of cases restored by GIC were higher than those restored by the other three materials.

Conclusions: Our study provided evidence that the clinical efficacy of flowable resin composites, Dyract compomers, and light-curing composite resin was greater than that of GIC for restoration of dental WSD.

MeSH Keywords: Composite Resins • Glass Ionomer Cements • Wedge Argument

Full-text PDF: <https://www.medscimonit.com/abstract/index/idArt/902937>



Background

Non-carious cervical lesion (NCCL), often termed as a “non-carious cervical tooth surface loss”, is a disease that is possibly the result of dental abrasions; the prevalence of NCCL increases with age, while occurrence rates vary in different populations [1]. Dental wedge-shaped defect (WSD) is classified as a typical type of NCCL (the other commonly seen NCCL type is saucer-shaped defect), and is attributed to hard dental tissue loss in cemento-enamel junction region, a region vulnerable to the influences of the environment owing to the extreme thin layer formed by the dental enamel in this region [2]. NCCL is of increasing clinical concern and presents a restorative challenge for dentists. One study looked at the prevention and restoration of NCCL through developing restorative materials which could minimize the operational damage and maximize the retention rate of NCCL restoration [3]. Among all the available restorative strategies, glass-ionomer-based material is considered a conventional choice for the majority of NCCL treatments; moreover, its composites and compomers have shown excellent efficacy in recent studies [4]. The present study aimed to compare the restorative efficacy of four restorative materials, including flowable resin composites, Dyract compomers, light-curing composite resin, and glass ionomer cement (GIC) in WSD restoration.

Both WSD and saucer-shaped lesions have a slim chance for retention and stability in restoration, therefore, restorative materials that are simple to operate are more desirable in the clinical restoration of WSD [5]. GIC is a classical material selected for WSD restoration as it can build a chemical adhesion to enamel and dentine [6]. However, there are still many unfavorable characteristics of GIC, including high moisture sensitivity, poor wear resistance, and esthetic properties [7]. Moreover, it has been demonstrated that although GIC has a high retention rate, it fails to protect the surface quality and porosity of teeth, thus there is an urgent need for new material development [8]. Flowable resin composite is a restorative material that shows a positive effect in the restoration of WSD owing to its low viscosity; it has been formulated in numerous composites to meet different requirements [9]. Compomers is another popular alternative for the restoration of WSD due to its outstanding appearance and wear resistance properties; and Dyract compomers is widely used due to its relatively low insensitivity to contamination [10]. Light-curing composite resin is a newly developed composite resin that is cost-effective and shows higher bond strength quality than polymer composite [11]. Through comparing the effects of the four materials, our study aim was to find out which material showed better efficacy in the restoration of dental WSD and improved the clinical outcome of WSD patients.

Material and Methods

Baseline characteristics

From September 2015 to September 2016, a total of 108 patients were admitted at the First Affiliated Hospital's Endodontics Department of the Medical School of Xi'an Jiaotong University; patients suffering from dental WSD in maxillary premolars were enrolled in the study. Inclusion criteria were as follows: 1) patients without any filling treatment; 2) patients suffering from maxillary premolars with dental WSD; 3) patients without any obvious symptoms; 4) patients with a normal pulp vitality and no caries lesion; 5) patients did not bleed during probing process; 6) patients with a normal occlusion, the WSD position being within subgingival 0 ~ 1 mm, with a defect deep into the middle layer of the dentin. Exclusion criteria were as follows: 1) patients with a history of systemic disease; 2) patients with poor oral hygiene conditions; 3) patients with periodontal disease; 4) patients with pulp disease; 5) patients taking antibiotics during illness; 6) patients whose filling materials fell off. Of the 108 patients were enrolled, two cases were excluded (due to loss of follow-up contact). The study thus included 280 maxillary premolars with dental WSD, from 106 patients (41 male patients and 65 female, between the ages of 21 and 65 years). Patients were divided into eight groups (n=35) according to WSD positions (approaching gingival position where the gingival wall margin was in approaching-gingiva or a subgingival position where the gingival wall margin was under the gingiva within 0~1 mm), and according to the four restorative materials. Group I was flowable resin composites + approaching gingival. Group II was light-curing composite resin + approaching gingival. Group III was Dyract compomer + approaching gingival. Group IV was GIC + approaching gingival. Group V was flowable resin composites + subgingival. Group VI was light-curing composite resin + subgingival, Group VII was Dyract compomer + subgingival. Group VIII was GIC + subgingival. The study was approved by the Ethical Committee of the First Affiliated Hospital, Medical School of Xi'an Jiaotong University. Informed consent was obtained from each participant.

Restoration procedure

For restoration procedures using flowable resin composites (Minnesota Mining and Manufacturing Corporation, Saint Paul City, MN, USA) the teeth with dental WSD were cleaned and disinfected in 50% ethyl alcohol. An absorbent ball was used for moisture protection, and pressurized air was used to dry the ethyl alcohol from the teeth. An appropriate amount of acid etching agent was added on for 30 seconds. The defect sites were filled in with the proper amount of flowable resin composites, and then the filling of flowable resin composite was ground, polished, and processed.

For restoration procedures using light-curing composite resin and acid etching agent (Gusha Biological Materials Ltd., Beijing, China) the teeth with dental WSD were cleaned and disinfected in 50% ethyl alcohol. An absorbent ball was used for moisture protection, and pressurized air was used to dry the ethyl alcohol from the teeth. An appropriate amount of acid etching agent was added for 30 seconds. Then the defect sites were filled with composite resin, synthesized by 0.6~1 μm and 0.04 μm of inorganic filler particles. UV-light curable adhesive and UV radiation curing were then used to make the fillings adhesive. When the fillings were solidly adhered to the teeth, they were then ground, polished, and processed.

For restoration procedures using Dyract compomer (Densply Co., New York City, NY, USA) the teeth with dental WSD were cleaned and disinfected in 50% ethyl alcohol. An absorbent ball was used for moisture protection and pressurized air was used to dry the ethyl alcohol from the teeth. Then a Prime & Bond NT binder (Densply Co., New York City, NY, USA) was spread on the defected site, 10 seconds later the binder was blown gently with air then put under illumination for 20 seconds. A proper amount of Dyract compomer was placed in the defected site, with light curing for 30 seconds. The filling Dyract compomer was ground, polished, and processed.

For restoration procedures using GIC (Qingbu Dental Materials Factory, Shanghai, China) the teeth with dental WSD were cleaned and disinfected in 50% ethyl alcohol. An absorbent ball was used for moisture protection, and pressurized air was used to dry the ethyl alcohol from the teeth. Based on the product instructions, GIC cement was used to fill in defected sites until it met the edge, while excessive filler was removed by microbe. The filling Dyract nanometer composite resin was ground, polished, and processed six minutes later, and an appropriate amount of Vaseline was spread on the teeth.

Specimen collection

The teeth with dental WSD were cleaned using sterilized cleaning equipment and observed after being protected from moisture and dried by an absorbent ball. Then a 2×10 mm PerioPaper GCF filter paper (Harco Electronic Ltd., Winnipeg, Manitoba, Canada) was weighed in an Eppendorf tube, then carefully nipped and inserted into the gingival sulcus 1 mm in depth close to the cheek of the teeth and distal lingual position and soaked for 30 seconds. The samples were taken from the same site 10 seconds later. After sampling, a Periotron 8000 admeasuring apparatus (Plainview Co., Plainview, NY, USA) was used to measure the gingival crevicular fluid (GCF) volume; the mean value of two measurements was taken as the final GCF volume. After recording, the GCF filter paper was put into an Eppendorf tube containing 200 μL of Tris-HCl buffer solution (0.1 mmol/L, pH=7.5, Sigma-Aldrich Chemical Company, St

Louis, MO, USA) and oscillated for one hour at 4°C, centrifuged (10,000 rev/min) for 10 minutes; then the supernatant was extracted and stored in a refrigerator at -20°C for further use.

Measurement of GCF-AST, GCF-ALP, and IL-1 β levels

The supernatant (80 μL) was extracted and a BS-2000M full automatic biochemical analyzer (Medical International Co., Ltd, Guangdong, China) was used to detect GCF-AST and GCF-ALP levels; all experimental procedures were in strict accordance with instructions. Another 120 μL of supernatant was taken for the detection of IL-1 β levels by enzyme-linked immunosorbent assay (ELISA) IL-1 β kit (Jingmei Biotechnology Ltd., Guangdong, China). Ten standard wells (including two blank control wells, without samples or enzyme labeled reagents) were set on the enzyme labeled plate, then standard curves were drawn following gradient dilution of the standard products, and the diluted samples were loaded into the sample wells on the enzyme labeled plate. After loading, the plate was sealed and the samples were gently shaken, mixed, and incubated for 30 minutes at 37°C. The fluid in the wells was then discarded and an appropriate amount of cleaning solution was added for 30 seconds. These steps were repeated five times, and the fluid was eventually discarded, followed by the addition of 50 μL of enzyme labeled reagent followed by incubation for 30 seconds at 37°C. The fluid in the wells was then discarded and cleaning solution was added for 30 seconds; these steps were repeated five times, and the fluid was eventually discarded. A total of 50 μL color developing reagent A and 50 μL color developing reagent B were mixed in each well and incubated for 15 minutes in the dark at 37°C, followed by the addition of 50 μL stopping solution. The value of the blank well was taken as 0, and the optical density (OD) value at the wavelength of 450 nm of each well was measured within 15 minutes. The microplate reader was purchased from Bio-Rad, Inc., Hercules, CA, USA.

Clinical examination of periodontal conditions

The periodontal clinical examination was performed by the same doctor with a labeled periodontal probe. Plaque index (PLI) was used to record the thickness and the number of plaque in the vicinity of the gingival margin as follows: 3 means gingival marginal plaque that extends to above 1/3 of the tooth surface; 2 means cervical marginal plaque that extends to no more than 1/3 of the tooth surface; 1 means no visible plaque, but a small amount of plaque in probing process; and 0 means no plaque. Probing depth (PD) was the degree of the deepest point in periodontal probing that was processed by the same doctor. Sulcus bleeding index (SBI) was as follows: 5 means gingival color change, swelling, sometimes with ulceration, automatic bleeding or bleeding on probing; 4 means gingival color change, swelling and bleeding on probing; 3 means gingival inflammatory color change, slight

swelling and bleeding on probing; 2 means gingival inflammatory color change, bleeding on probing, but no swelling; 1 means healthy gingival sulcus appearance, but gently bleeding on probing; and 0 means healthy gingival sulcus appearance, but no bleeding on probing.

Efficacy evaluation

The periodontal conditions of all patients were followed for six months and 12 months after restoration; oral and dental disease examinations as well as endodontic experiments were conducted on the teeth. The clinical results were evaluated according to the U.S. Public Health Service (USPHS) standards. Criteria for successful treatment were as follows: complete structure of the filling material, closed margin, smooth surface, no gap or staining, no felling, caries or pain, no allergies to hot and cold stimuli, no conscious symptoms in the patient, and normal pulp vitality. The treatment would be considered a failure if any of the aforementioned requirements were not met [12]. The evaluation standards for color coordination were as follows: dental implants and teeth were in normal range either in color, translucency, or shading. The leakage detection method was used for edge density, observing the morphology, depth, and area and volume of effusion, and then given a relative grade.

Statistical analysis

All data were analyzed by SPSS (SPSS Inc., Chicago, IL, USA) 21.0 statistical software. The count data were represented by number and percentage, and the measurement data were expressed with mean \pm standard deviation (SD) ($\bar{x}\pm s$). The paired *t*-test was applied in the comparisons of two groups (pre-restoration and six months after restoration, pre-restoration and 12 months after restoration), with $p<0.05$ indicating statistically significant.

Results

Clinical evaluation of the four restorative materials for restoration of WSD by USPHS

After six months of restoration (one case was excluded due to loss of follow-up contact), the overall clinical success rates for repairing the edge position of the same gingival wall of flowable resin composites and light-curing composite resin were greater than those of GIC (all $p<0.05$). After 12 months of restoration (two cases were excluded due to loss of follow-up contact), the overall clinical success rates of flowable resin composites were greater compared to those of light-curing composite resin and GIC (all $p<0.05$). In addition, after six and 12 months of restoration, the overall clinical success rates of

flowable resin composites and light-curing composite resin in the restoration of approaching gingival WSD and subgingival WSD were not significantly different (all $p>0.05$), while the overall clinical success rate of GIC in the restoration of approaching gingival WSD was significantly higher than those in the restoration of subgingival WSD, thus at the same time, the overall clinical success rate of GIC reached the lowest comparison with other three materials (all $p<0.05$) (Table 1).

Comparison of GCF volume before and after six and 12 months of restoration in each group

After six and 12 months of restoration, GCF volume in each group was significantly increased compared to before restoration (all $p<0.05$), and the GCF volume in each group after 12 months of restoration was higher than after six months of restoration. The GCF volume in the GIC group (restoration of approaching gingival and subgingival WSD) was higher than in the flowable resin composites, light-curing composite resin, and Dyract compomers groups (restoration of approaching gingival and subgingival WSD) (all $p<0.05$). In addition, after six and 12 months of restoration, the GCF volume in the flowable resin composites, light-curing composite resin, and Dyract compomers groups (restoration of approaching gingival WSD) was not significantly different from the GCF volume in the restoration of subgingival WSD at the given times (all $p>0.05$), while the GCF volume in the GIC group (restoration of subgingival WSD) was revealed to be higher than that in the restoration of approaching gingival WSD by the same material six months and 12 months after restoration (all $p<0.05$) (Table 2). GCF volume, as the inflammatory exudates of periodontal tissue, can reflect periodontal health. Among the four materials, WSD lead to higher GCF volume, and in restoration of subgingival WSD it increased in a most significant way, indicating that WSD can result in inflammatory reaction in a remarkable way.

Comparison of levels of GCF-AST, GCF-ALP, and IL-1 β in GCF before and after six and 12 months of restoration in each group

After six months of restoration, in the flowable resin composites, light-curing composite resin, and Dyract compomers groups, the GCF-AST level was significantly higher than the GCF-AST level before restoration (all $p<0.05$), while levels of GCF-ALP and IL-1 β after six months of restoration were not significantly different ($p>0.05$). The levels of GCF-AST, GCF-ALP, and IL-1 β in the GIC group were significantly higher after than before restoration ($p<0.05$). After six months of restoration, the levels of GCF-AST, GCF-ALP, and IL-1 β were higher in the GIC group compared with the flowable resin composites, light-curing composite resin, and Dyract compomers groups ($p<0.05$), while after 12 months of restoration they were higher in each group (all $p<0.05$). GCF-AST, GCF-ALP, and IL-1 β levels in the

Table 1. The overall clinical success rate of the four restorative materials for restoration of WSD after 6 and 12 months of restoration (%).

Items	Time (month)	Groups							
		Group I	Group II	Group III	Group IV	Group V	Group VI	Group VII	Group VIII
Fixation	6	97.14	80.00	91.43	74.29	91.43	77.14	88.57	40.00
	12	91.43	71.43	82.86	62.86	85.71	71.43	80.00	37.14
Color harmony	6	91.43	77.14	85.71	71.43	88.57	74.29	85.71	37.14
	12	85.71	74.29	74.29	45.71	82.86	68.57	77.14	25.71
Marginal staining	6	94.29	88.57	88.57	65.71	91.43	85.71	88.57	42.86
	12	88.57	77.14	82.86	62.86	85.71	74.29	82.86	17.14
Marginal sealability	6	91.43	77.14	77.14	68.57	91.43	74.29	80.00	28.57
	12	82.86	71.43	71.43	45.71	82.86	65.71	71.43	20.00
Surface feature	6	94.29	91.43	91.43	42.86	94.29	88.57	82.86	45.71
	12	88.57	77.14	77.14	45.71	80.00	74.29	74.29	37.14
Secondary caries	6	100.00	82.86	85.71	62.86	100.00	80.00	82.86	34.29
	12	94.29	85.71	88.57	54.29	100.00	82.86	88.57	22.86
Dental pulp reaction	6	100.00	94.29	97.14	48.57	97.14	82.86	94.29	37.14
	12	82.86	82.86	82.86	42.86	85.71	68.57	80.00	28.57
Overall clinical success rate	6	95.51*	84.49*	88.16*	62.04	93.47*	80.41*	86.12*	37.96 [‡]
	12	87.76 [#]	77.14	80.00 [#]	51.43	86.12 [#]	72.24	79.18 [#]	26.94 [‡]

Group I, flowable resin composites + approaching gingival group; Group II, light-curing composite resin + approaching gingival group; Group III, Dyract compomers + approaching gingival group; Group IV, glass ionomer cement + approaching gingival group; Group V, flowable resin composites + subgingival group; Group VI, light-curing composite resin + subgingival group; Group VII, Dyract compomers + subgingival group; Group VIII, glass ionomer cement + subgingival group. * $P < 0.05$, compared with glass ionomer cement in restoration of WSD at the same position after 6 months of restoration; [#] $P < 0.05$, compared with light-curing composite resin and glass ionomer cement in restoration of WSD at the same position after 12 months of restoration; [‡] $P < 0.05$, compared with restoration of approaching gingival WSD with the same restorative material; WSD – wedge-shaped defect.

GIC group (restoration of approaching gingival and subgingival WSD) were significantly higher than those in the flowable resin composites, light-curing composite resin, and Dyract compomers groups for WSD restoration at the same position (all $p < 0.05$). After six and 12 months of restoration, the levels of GCF-AST, GCF-ALP, and IL-1 β in the flowable resin composites, light-curing composite resin, and Dyract compomers groups for subgingival WSD restoration were not significantly different from those in the same groups for approaching gingival WSD restoration (all $p > 0.05$), while the levels of GCF-AST, GCF-ALP, and IL-1 β in the GIC group for subgingival WSD restoration were significantly increased compared with those in the GIC group for approaching gingival WSD restoration ($p < 0.05$) (Tables 3–5). The levels of GCF-AST, GCF-ALP, and IL-1 β in the GIC group for subgingival WSD restoration were significantly increased compared to the other three materials, suggesting that periodontal cells were destroyed in the most significant

way. Among the other three groups, there was no significant difference in the levels of ALP and IL-1 β , showing WSD exerted a relative light effect on the periodontal cells.

Comparison of the periodontal conditions before and after six and 12 months of restoration in each group

After six and 12 months of restoration, the PLI, PD, and SBI in the flowable resin composites, light-curing composite resin, and Dyract compomers groups were not significantly increased compared to before restoration (all $p > 0.05$), whereas after 12 months of restoration, the PLI, PD, and SBI in the GIC group were significantly increased compared to before and after six months of restoration (all $p < 0.05$). And six and 12 months after restoration, the PLI, PD, and SBI in the GIC group (restoration for approaching gingival and subgingival WSD) were significantly higher than those in the flowable resin composites, light-curing composite

Table 2. Comparison of GCF volume before and after 6 and 12 months of restoration in each group.

Groups	Before restoration	After 6 months of restoration	After 12 months of restoration
Group I	0.985±0.121	1.197±0.208*	1.327±0.236*#
Group II	1.005±0.135	1.203±0.211*	1.329±0.233*#
Group III	1.059±0.196	1.184±0.106*	1.299±0.215*#
Group IV	1.067±0.201	1.403±0.320* [§]	1.595±0.390*# [§]
Group V	0.978±0.116	1.189±0.117*	1.358±0.225*#
Group VI	1.049±0.127	1.186±0.179*	1.298±0.213*#
Group VII	1.001±0.093	1.209±0.108*	1.334±0.221*#
Group VIII	1.036±0.102	1.587±0.392* [§] &	1.836±0.520*# [§] &

Group I, flowable resin composites + approaching gingival group; Group II, light-curing composite resin + approaching gingival group; Group III, Dyract compomers + approaching gingival group; Group IV, glass ionomer cement + approaching gingival group; Group V, flowable resin composites + subgingival group; Group VI, light-curing composite resin + subgingival group; Group VII, Dyract compomers + subgingival group; Group VIII, glass ionomer cement + subgingival group. * $P < 0.05$, compared with GCF volume before treatment; # $P < 0.05$, compared with GCF volume after 6 months of restoration; [§] $P < 0.05$, compared with flowable resin composites, light-curing composite resin and Dyract compomers restoration groups for the restoration of WSD at the same position; & $P < 0.05$, compared with restoration of approaching gingival WSD with the same restorative material; WSD – wedge-shaped defect; GCF, gingival crevicular fluid.

Table 3. Comparison of GCF-AST level before and after 6 and 12 months of restoration in each group ($\bar{x} \pm s$, IU/L, n=35).

Groups	Before restoration	After 6 months of restoration	After 12 months of restoration
Group I	400.79±35.36	430.25±39.98*	456.13±40.32*#
Group II	405.21±40.25	429.21±37.04*	455.47±48.31*#
Group III	398.42±32.17	435.62±42.25*	465.12±53.26*#
Group IV	387.59±30.25	470.14±50.27* [§]	506.92±66.38*# [§]
Group V	411.21±40.12	438.32±40.06*	465.15±47.38*#
Group VI	395.71±29.52	437.85±49.77*	468.12±49.73*#
Group VII	400.08±30.59	440.17±53.65*	470.32±53.28*#
Group VIII	409.52±36.47	509.63±56.57* [§] &	546.69±60.58*# [§] &

Group I, flowable resin composites + approaching gingival group; Group II, light-curing composite resin + approaching gingival group; Group III, Dyract compomers + approaching gingival group; Group IV, glass ionomer cement + approaching gingival group; Group V, flowable resin composites + subgingival group; Group VI, light-curing composite resin + subgingival group; Group VII, Dyract compomers + subgingival group; Group VIII, glass ionomer cement + subgingival group. * $P < 0.05$, compared with GCF-AST level before treatment; # $P < 0.05$, compared with GCF-AST level after 6 months of restoration; [§] $P < 0.05$, compared with flowable resin composites, light-curing composite resin and Dyract compomers restoration groups for the restoration of WSD at the same position; & $P < 0.05$, compared with restoration of approaching gingival WSD with the same restorative material; WSD – wedge-shaped defect; GCF – gingival crevicular fluid; AST – aspartate aminotransferase.

resin, and Dyract compomers groups for WSD restoration at the same position (all $p < 0.05$). After six and 12 months of restoration, the PLI, PD, and SBI in the flowable resin composites, light-curing composite resin, and Dyract compomers groups (restoration of subgingival WSD) were not significantly different from those in restoration of approaching gingival WSD by the same materials (all $p > 0.05$), while after six months of restoration, PLI

in the GIC group for subgingival WSD restoration was significantly increased compared to the GIC group for approaching gingival WSD restoration ($p < 0.05$), and after 12 months of restoration, SBI in the GIC group for subgingival WSD restoration was higher than the approaching gingival WSD restoration by the same material, indicating that WSD fillings exerted a negative effect on periodontal tissues ($p < 0.05$) (Table 6).

Table 4. Comparison of GCF-ALP level before and after 6 and 12 months of restoration in each group ($\bar{x}\pm s$, IU/L, n=35).

Groups	Before restoration	After 6 months of restoration	After 12 months of restoration
Group I	133.48±15.27	137.47±16.25	159.15±19.32**
Group II	138.43±17.15	140.67±18.16	160.70±20.12**
Group III	140.08±19.71	141.82±20.56	163.12±20.56**
Group IV	135.85±13.64	157.22±21.78* ⁵	185.21±23.59** ⁵
Group V	132.69±12.76	138.52±13.75	165.21±21.46**
Group VI	139.83±14.09	141.52±24.63	163.47±20.58**
Group VII	129.76±12.41	137.31±13.52	159.32±18.52**
Group VIII	136.18±14.22	173.28±26.17* ⁵ &	199.62±27.98** ⁵ &

Group I, flowable resin composites + approaching gingival group; Group II, light-curing composite resin + approaching gingival group; Group III, Dyract compomers + approaching gingival group; Group IV, glass ionomer cement + approaching gingival group; Group V, flowable resin composites + subgingival group; Group VI, light-curing composite resin + subgingival group; Group VII, Dyract compomers + subgingival group; Group VIII, glass ionomer cement + subgingival group. * $P < 0.05$, compared with GCF-ALP level before treatment; # indicates a comparison with GCF-ALP level after 6 months of restoration; ⁵ $P < 0.05$, compared with flowable resin composites, light-curing composite resin and Dyract compomers restoration groups for the restoration of WSD at the same position; & $P < 0.05$, compared with restoration of approaching gingival WSD with the same restorative material; WSD – wedge-shaped defect; GCF – gingival crevicular fluid; ALP – alkaline phosphatase.

Table 5. Comparison of IL-1 β level before and after 6 and 12 months of restoration in each group ($\bar{x}\pm s$, IU/L, n=35).

Groups	Before restoration	After 6 months of restoration	After 12 months of restoration
Group I	8.12±1.64	8.39±1.65	10.32±2.51**
Group II	8.23±1.71	8.58±1.73	9.76±2.45**
Group III	7.31±1.05	7.72±1.53	9.52±2.14**
Group IV	8.14±1.67	11.37±2.15* ⁵	13.95±3.04** ⁵
Group V	7.85±1.36	8.23±1.27	10.17±2.43**
Group VI	7.96±1.42	8.79±1.56	11.75±2.93**
Group VII	8.08±1.49	8.13±1.35	10.74±2.43**
Group VIII	7.95±1.39	15.04±3.76* ⁵ &	17.21±3.98** ⁵ &

Group I, flowable resin composites + approaching gingival group; Group II, light-curing composite resin + approaching gingival group; Group III, Dyract compomers + approaching gingival group; Group IV, glass ionomer cement + approaching gingival group; Group V, flowable resin composites + subgingival group; Group VI, light-curing composite resin + subgingival group; Group VII, Dyract compomers + subgingival group; Group VIII, glass ionomer cement + subgingival group. * $P < 0.05$, compared with IL-1 β level before treatment; # $P < 0.05$, compared with IL-1 β level after 6 months of restoration; ⁵ $P < 0.05$, compared with flowable resin composites, light-curing composite resin and Dyract compomers restoration groups for the restoration of WSD at the same position; & $P < 0.05$, compared with restoration of approaching gingival WSD with the same restorative material; WSD – wedge-shaped defect; IL-1 β – interleukin-1 β .

Discussion

WSD is a disease that could be the result of various causes, including erosion and abrasion; and stress erosion is acknowledged as the major cause of WSD [13]. Restorative treatment has been demonstrated as an effective management strategy for WSD, but controversies still exist regarding the most suitable

material [4]. Our paper focused on comparing four widely used restorative materials in the restoration of WSD, aiming to figure out the efficacy of the four materials while shedding a little light on the best material choice for dental WSD restoration.

First, through clinical evaluation based on USPHS, our study provided evidence that GIC presented poorer restoration efficacy

Table 6. Comparison of the periodontal conditions before and after 6 and 12 months of restoration in each group ($\bar{x}\pm s$).

		Group I	Group II	Group III	Group IV	Group V	Group VI	Group VII	Group VIII
Before restoration	PLI	0.59±0.08	0.58±0.07	0.62±0.11	0.64±0.15	0.57±0.06	0.63±0.14	0.60±0.09	0.64±0.12
	PD (mm)	1.42±0.19	1.45±0.22	1.49±0.28	1.38±0.17	1.51±0.32	1.43±0.21	1.54±0.33	1.40±0.15
	SBI	0.53±0.10	0.58±0.12	0.53±0.13	0.54±0.15	0.60±0.21	0.62±0.26	0.57±0.13	0.59±0.15
After 6 months of restoration	PLI	0.58±0.08	0.59±0.09	0.643±0.12	0.81±0.22 [§]	0.63±0.15	0.66±0.17	0.64±0.12	1.03±0.32 ^{§&}
	PD (mm)	1.45±0.22	1.46±0.24	1.50±0.36	1.83±0.40 [§]	1.49±0.32	1.47±0.31	1.55±0.31	1.90±0.46 [§]
	SBI	0.56±0.11	0.59±0.13	0.55±0.10	0.93±0.16 [§]	0.62±0.15	0.63±0.27	0.58±0.15	1.02±0.32 [§]
After 12 months of restoration	PLI	0.60±0.09	0.61±0.10	0.64±0.13	1.03±0.46 [§]	0.64±0.12	0.67±0.18	0.645±0.15	1.10±0.34 [§]
	PD (mm)	1.46±0.23	1.47±0.22	1.52±0.38	1.86±0.42 ^{§#}	1.50±0.34	1.48±0.26	1.56±0.32	1.93±0.48 [§]
	SBI	0.58±0.13	0.60±0.14	0.56±0.11	1.25±0.42 ^{§*#&}	0.64±0.16	0.64±0.28	0.61±0.17	1.56±0.57 ^{§*#&}

Group I, flowable resin composites + approaching gingival group; Group II, light-curing composite resin + approaching gingival group; Group III, Dyract compomers + approaching gingival group; Group IV, glass ionomer cement + approaching gingival group; Group V, flowable resin composites + subgingival group; Group VI, light-curing composite resin + subgingival group; Group VII, Dyract compomers + subgingival group; Group VIII, glass ionomer cement + subgingival group. * $P<0.05$, compared with periodontal conditions before treatment; # $P<0.05$, compared with periodontal conditions after 6 months of restoration; [§] $P<0.05$, compared with flowable resin composites, light-curing composite resin and Dyract compomers restoration groups for the restoration of WSD at the same position; & $P<0.05$, compared with restoration of approaching gingival WSD with the same restorative material; WSD – wedge-shaped defect; PD – probing depth; PLI – plaque index; SBI – sulcus bleeding index.

than the other three materials. When conducting a clinical evaluation on the restoration effects of a restorative material, there are many aspects that need to be taken into consideration, including retention rate, marginal characteristics, material deterioration, secondary caries, color stability, and biological effects [14]. GIC is a conventional dental restorative material with numerous advantages such as its fluoride-releasing property and the ease of placement into gingival cavities. But at the same time, GIC does not only lack strength and toughness, it fails to maintain its stability in an acidic environment as it does in pure water, indicating that degradation in an acidic environment is a shortcoming that cannot be ignored for a dental restorative material [15]. Yang et al. demonstrated in a study on the pulp revascularization for periapical surgery that coronal sealing was achieved by GIC and composite resin [16]. Another study found that a part of the root could be repaired with resin-modified GIC and the restorative defect could be debrided [17]. In addition, a study demonstrated that after GIC was modified by resin (i.e., resin-modified GIC) the performance, in terms of retention rate, secondary caries, and postoperative sensitivity, was significantly improved. However, it should be noted that resin-modified GIC is an area that still needs further study [14]. Periodontal conditions and secondary caries have been reported as having associations with composite resin copings (RCs) for abutment teeth [18]. In addition, secondary caries lesions are regarded as a complication of dental restorations, which thus limits their life span and increases cost by repeated re-interventions; accurate detection of secondary lesions is a significant consideration for

allocating appropriate treatments and estimating the burden of disease [19]. One study that investigated the role of orthodontic force in dental pulp cells leading to circulatory disturbances in the dental pulp in a rat model found that pulp tissue might undergo a remodeling process [20]. Another study indicated that the upregulation of secretion of both anti- and pro-inflammatory cytokines in rat dental pulp was followed by tooth replantation [21]. Taken together with our study results, we concluded that GIC had a poorer restoration efficacy compared to the other three materials.

In addition, we also found that in the patients with restoration by GIC, the GCF volume, GCF-AST, GCF-ALP, and IL-1 β levels were higher than those with restoration by the other three materials. In addition, the periodontal conditions were poorer than those who underwent restoration by the other three materials. Dental WSD has been linked with gingival inflammation caused by disorders of immune system and inflammatory responses, and cytokines are considered important regulatory proteins in immune cells. Moreover, it has been suggested that cytokines in GCF are closely associated with diagnosis and prognosis of periodontal destruction, among which IL-1 β cytokine is reported to be increased in periodontal disease [22]. In an initial study based on an Indian population, it was pointed out that IL-1 β level was remarkably elevated in inflammation sites compared to healthy sites, and Satio et al. suggested that IL-1 β production could be downregulated by platelet granule extract 2 [23]. Other enzymes in saliva, including AST and ALP, have also been reported to play important roles in periodontal

diseases such as WSD, and the activity of AST and ALP have been found to be upregulated in patients with periodontal destruction [24]. It was also shown that a high level of GCF-AST was related to a variety of periodontal destruction symptoms, including periodontal pockets and bleeding and suppuration in the gingiva [25]. ALP has been proposed as a host enzyme which can indicate the periodontal healing/recurrent progression phase in patients with chronic periodontal disease [26]. Moreover, the increased expression of ALP indicates that even the alveolar bone is affected by the process of pathological destruction, suggesting an advanced stage of periodontal disease [27]. Based on our findings, WSD patients restored by GIC presented high GCF volume, as well as high levels of GCF-AST, GCF-ALP, and IL-1 β , thus resulting in the finding that GIC is not an ideal choice for WSD restoration.

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Conclusions

All in all, the WSD cases restored by GIC presented increased GCF volume and the levels of GCF-AST, GCF-ALP, and IL-1 β , and the poorer periodontal conditions compared to those treated with the other three materials, suggested that the clinical success rates of flowable resin composites, Dyract compomers, and light-curing composite resin were greater than those of GIC for the restoration of dental WSD. Thus, we concluded that flowable resin composites, Dyract compomers, and light-curing composite resin were favorable substitutes for GIC. However, further studies regarding the advantages and disadvantages of the three novel materials in WSD restoration are needed.

Competing interests

None.