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Fluorescence-aided Composite Removal in Directly Restored Permanent Posterior Teeth

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Clinical Relevance

The fluorescence-aided identification technique can be a useful and time-saving aid for the repair and replacement of direct composite restorations with the potential to preserve tooth substance and reduce the risk of treatment-related complications.

SUMMARY

Aim: The aim of this study was to quantitatively compare conventional composite removal and composite removal supported by the fluorescence-aided identification technique (FIT) regarding the completeness, selectivity, and duration of the procedure in directly restored permanent posterior teeth.

Methods and Materials: Two operators removed standardized direct class II composite restorations (n=32 per operator) in human tooth models under simulated clinical conditions. According to a randomized allocation scheme, removal was performed with either the conventional technique (contra-angle handpiece) or supported by FIT. The duration of each removal procedure was recorded. The completeness and selectivity were volumetrically assessed through superimposition of three-dimensional surface scans. Statistical significance was tested by examining the overlap of 95% confidence intervals (CI). Multiple comparison was performed with Tukey tests for each variable.

Results: Compared with the conventional technique, composite removal with FIT was faster (329 seconds [95% confidence interval (CI): 268-390 seconds] vs 179 seconds [95% CI: 150-208 seconds]), generated less tooth substance loss (4.53 mm^3 [95% CI: 3.77-5.30 mm^3] vs 2.77 mm^3 [95% CI: 2.11-3.43 mm^3]), and left behind less

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composite residue (1.58 mm^3 [95% CI: 1.23-1.94 mm^3] vs 0.53 mm^3 [95% CI: 0.39-0.67 mm^3]).

Conclusion: Within the limitations of this *in vitro* study, FIT facilitated the selective and expeditious removal of tooth-colored composites in directly restored posterior teeth.

INTRODUCTION

Composites are now the material of choice for direct posterior restorations because of their good clinical performance and esthetic properties.[1,2] However, restorations have a limited lifespan, with secondary caries and fractures being the predominant reasons for the failure of posterior composite restorations.[2,3] The replacement of failing and defective restorations is therefore a commonplace procedure: replacement restorations account for more than half of restorations placed by dentists.[1,4] Refurbishment and repair are restorative treatment approaches that, underpinned by a considerable body of evidence, can extend the lifespan of direct composite restorations.[5-8] Nevertheless, partially defective composite restorations are frequently treated with the replacement of the entire restoration.[2,9]

Removal of composite with an exact color match can pose a formidable challenge in restorative dentistry; inadvertent removal of adjacent dental hard tissue often is all but inevitable.[10] As a consequence, a cavity tends to increase in size with each invasive intervention, which may, in turn, negatively affect the long-term prognosis of a tooth.[4,11-13]

Different avenues have been explored to facilitate the selective removal of tooth-colored composites. For instance, carbon dioxide lasers guided by spectral feedback allow a higher level of ablation selectivity compared with the traditional composite removal with a high-speed handpiece.[14] Another approach, termed fluorescence-aided identification technique (FIT), uses the fluorescence properties of composites to make them more easily detectable and thus facilitate their selective removal.[10,15] Within the visible light spectrum, many composite materials have distinct fluorescence properties from dental hard tissues at wavelengths in the range of 405 $\pm$ 10 nm.[16] Consequently, the use of an illumination source emitting blue light in this range facilitates visually distinguishing between composite and tooth substance.[15] Recent studies have reported the successful application of FIT for orthodontic debonding procedures and the removal of composite bonded trauma splints.[17-19]

When providing replacement restorations and repairing partially defective restorations, it is crucial to avoid inadvertent removal of sound dental hard tissue. The aim of this *in vitro* study was therefore to quantitatively compare conventional composite removal and composite removal aided by FIT regarding the completeness, selectivity, and duration of the composite removal procedure in directly restored permanent posterior teeth.

METHODS AND MATERIALS

Model Preparation

From a pool of irreversibly anonymized human teeth, 32 permanent teeth were selected to produce a maxillary and mandibular model with a complete set of teeth. The teeth, stored in a 0.2% thymol solution, were free of caries, restorations, and significant signs of tooth wear. The setup of the dental arches was done in wax. An impression of the setup was taken with C-silicone putty material (Coltoflax, Coltène/Whaledent AG, Altstätten, Switzerland). The root ends were cut off, and a dowel pin (BI-PIN, Renfert GmbH, Singen, Germany) was fixed to each root with DuraLay (Reliance Dental Manufacturing LLC, Alsip, IL, USA). The model was produced according to the laboratory procedures required for a full arch master model with removable dies. The base of the model was cast with a self-curing denture base material (ProBase Cold, Ivoclar Vivadent AG, Schaan, Liechtenstein). The dowel pins attached to the root ends permitted either anchorage to the base or separate removal of each tooth from the base. A pink-colored gingiva mask was fabricated with an addition curing silicone (Gingiform 05410, BISCO Dental Products, Schaumburg, IL, USA).

Imaging

Optical surface scans were made with a five-axis dental laboratory scanner (inEOS X5, Dentsply Sirona Inc, York, PA, USA) at baseline and before and after each restorative procedure. The experimental design of the study is outlined in Figure 1. To ensure unobstructed scanning of the class II cavities, the neighboring teeth were removed from the base. Therefore, two scans per jaw model were made in each imaging session: maxillary/mandibular model with first premolars and first and third molars in place; maxillary/mandibular model with second premolars and second molars in place and canines removed.

Restorative Procedure

Before the cavity preparation, an impression of each posterior tooth was taken with a clear two-compo-

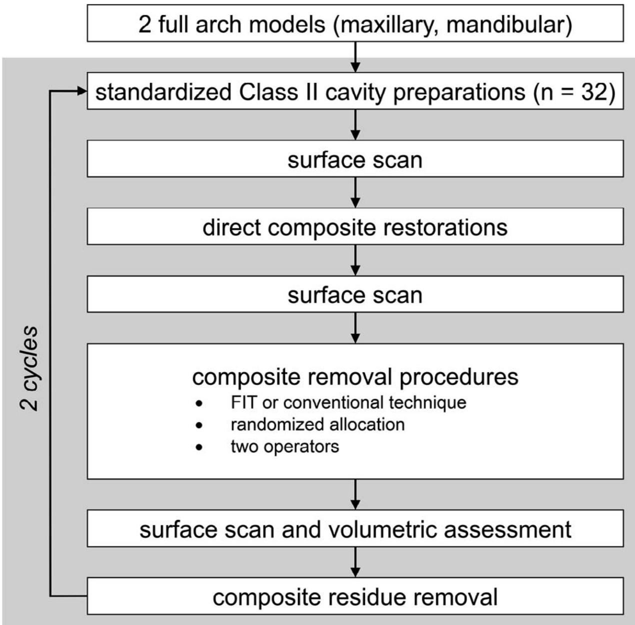
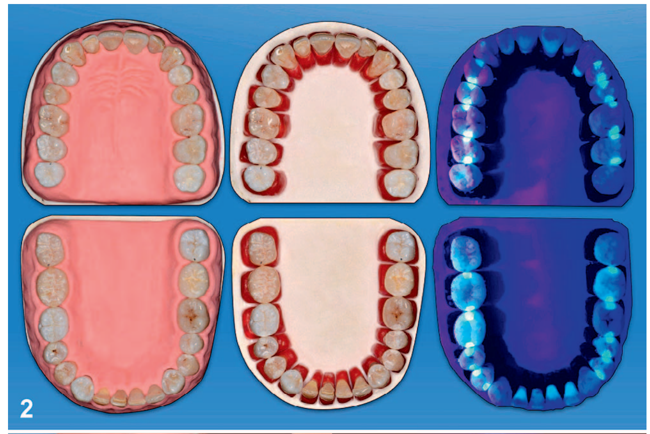


Figure 1. *Study flow diagram.*

nent silicone (SHERACRYSTAL, SHERA Werkstoff-Technologie GmbH & Co KG, Lemförde, Germany). The silicone impressions were trimmed to obtain keys with a uniform proximal thickness of about 3 mm. These silicone keys were used to provide direct composite restorations that replicated the original form of the proximal surface and marginal ridge.[20] To determine the base shade of the teeth, measurements were carried out on the central part of the proximal tooth surfaces with an intraoral spectrophotometer (VITA Easyshade V, VITA Zahnfabrik H. Rauter GmbH & Co KG, Bad Säckingen, Germany). The matching composite was selected for each class II cavity according to the corresponding shade measurement. Standardized class II cavities were prepared on the mesial and distal surfaces of all posterior teeth apart from the third molars for a total of 32 cavities. The cavities were prepared under constant water cooling with an ultrasonic preparation device (SIROPREP M2/D2 Standard, Dentsply Sirona Inc) in the region of the bucco-lingual position of the contact to the adjacent tooth. The approximate dimensions of the box-shaped cavities were as follows: the cavities were 2.7 mm wide in the bucco-lingual dimension, 1.6 mm mesio-distally, and 4 mm deep, with the gingival depth extending below the contact area. The gingival floor of the proximal boxes was located above the cementum-enamel junction. Cavity margins were not beveled.[21] The cavities were conditioned with a phosphoric acid etchant (Ultra-Etch, Ultradent



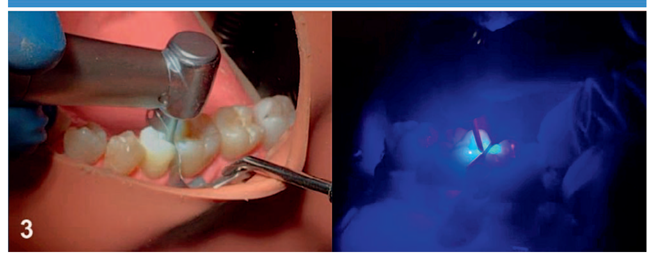


Figure 2. *Maxillary and mandibular full arch models with gingiva mask in place (left), with gingiva mask removed to show the separately removable teeth (middle), and under FIT illumination (right).*

Figure 3. *Conventional composite removal (left) and composite removal supported by FIT (right) under simulated clinical conditions.*

Products Inc, South Jordan, UT, USA), and an etch-and-rinse adhesive was applied according to the manufacturer's instructions (OptiBond FL, Kerr Italia Srl, Scafati, Italy). Light curing was performed for 20 seconds at 1200 mW/cm^2 (Bluephase, Ivoclar Vivadent AG). The pretreated class II cavities were filled in one increment with a nanohybrid direct composite material (IPS Empress Direct, Ivoclar Vivadent AG). Composite was applied in slight excess in the silicone key, which was then seated onto the tooth under constant finger pressure. Light curing was performed through the clear silicone key for 40 seconds at 1200 mW/cm^2 and after removing the silicone key for another 40 seconds at same output intensity (Bluephase, Ivoclar Vivadent AG). Excess material was removed with surgical scalpel blades (No. 12D, Gebrüder Martin GmbH & Co KG, Tuttlingen, Germany) under an operating microscope (OPMI PROergo, Carl Zeiss AG, Oberkochen, Germany). Figure 2 shows the model with and without the gingiva mask and under FIT illumination.

Operators 1 and 2 (FE and LM, respectively), two general dentists with normal vision, were tasked to completely remove the class II restorations without extending the cavities. Both operators had no color vision deficiency, which was assessed beforehand with Ishihara plates. Operators 1 and 2 had four and two years of professional experience, respectively.

The 32 restorations were evenhandedly assigned to the operators: each operator was responsible for 16 restorations, with an equal distribution of tooth types (premolars, molars), maxillary and mandibular teeth, right and left teeth, and mesial and distal restorations. Each operator performed the removal procedures in two sessions. Between the sessions, the volumetric assessment was undertaken, and the removed restorations were replaced (details see below). Both operators removed each restoration conventionally and with FIT (ie, 2 × 16 removal procedures per operator; Figure 3). A randomized allocation scheme, generated with online freeware (www.randomizer.org), determined for each restoration which technique to use first.

To simulate a clinical situation, the models were mounted in a dental manikin (P-6, Frasaco GmbH, Tettnang, Germany) whose head position was vertically and laterally adjustable. A single-ended shepherd's hook explorer, a dental mirror, and a triple function syringe were placed at the disposal of the operators. For conventional composite removal, the operators used a high-speed contra-angle handpiece (1:5, KaVo Master Series, KaVo Dental GmbH, Biberach, Germany) with a set of piriform, cylindrical and flame-shaped diamond burs (ISO 314 235 524 010, ISO 314 157 524 011, ISO 314 158 504 013, and ISO 314 248 514 011, Intensiv SA, Montagnola, Switzerland). For composite removal with FIT, a modified micromotor that was equipped with a light source emitting blue light at a wavelength of 405 nm was used (MX2, Bien-Air Dental SA, Bienne, Switzerland; Power LED LZ1-00UB00-00U7, LED Engin Inc, San Jose, CA, USA), and the operators had the same contra-angle handpiece and set of burs at their disposal (Figure 3). To protect adjacent teeth from iatrogenic damage, preventive stainless-steel aids with a thickness of 0.2 mm were used during composite removal (InterGuard, Ultradent Products Inc). Clear protective glasses were worn during the removal procedures. The operators used neither optical magnification devices nor filter lenses. The time for each removal procedure was recorded.

After the first session, an investigator (CD) examined the cavities with a FIT illumination source under an operating microscope and removed composite remnants in cavities where the removal procedure did not achieve complete composite removal with the same ultrasonic preparation device as used for the initial preparations. The cavities were finished with the ultrasonic preparation device to obtain class II cavities of substantially the same dimensions as in the first session and to have finished tooth substance as adhesion substrate for the following composite restoration. The direct composite restorations were made following the very same procedure as described above.

Volumetric Assessment

Obtained data from the optical scans were uploaded as surface tessellation language (STL) files to the OraCheck Software (Version 2.13.8676, Cyfex AG, Zurich, Switzerland). Technique allocation was concealed to the investigators (CD, TC) who carried out the quantitative assessments with OraCheck software. The best-fit method was used to superimpose scans.[22] Each tooth surface of interest was separately selected and overlapped independently from other surfaces to obtain a more accurate superimposition. A software tool with a color-coded scale clearly visualized volumetric changes between the scans: green marked unchanged areas; blue and violet colors indicated substance loss; and yellow, red, and pink indicated excess material. The cavities were analyzed using software tools that performed linear and volumetric measurements of selected areas (Figure 4). Areas of interest (ie, the class II cavities) were selected and analyzed with the "volume analysis" tool. Volumes were measured in cubic millimeters. The "cursor-distance" tool was used to quantify hard tissue defects, defined as any loss of dentin and/or enamel, and composite remnants. The highest and lowest points were recorded followed by a volumetric measurement.

Statistical Analysis

For each operator and removal technique, a descriptive analysis regarding volume of tooth substance defects, volume of composite residue, and treatment duration was performed. Statistically significant differences were expressed by nonoverlapping 95% confidence intervals (CIs). Multiple comparison was performed with Tukey tests for each variable with the level of significance set at 5%. Statistical analyses were conducted with JMP 11 (SAS Institute Inc, Cary, NC, USA). The relevant datasets are available on request.

RESULTS

The mean preoperative volume of the composite restoration was 16.65 mm^3 (SD: 2.23; 95% CI: 15.85-17.45) for the conventional technique and 16.91 mm^3 (SD: 2.05; 95% CI: 16.17-17.63) for the FIT group.

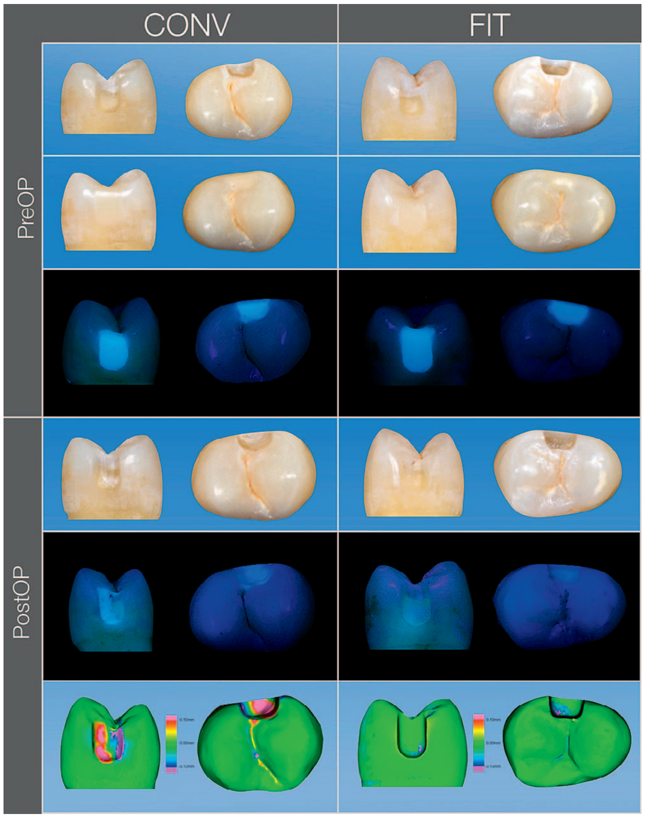
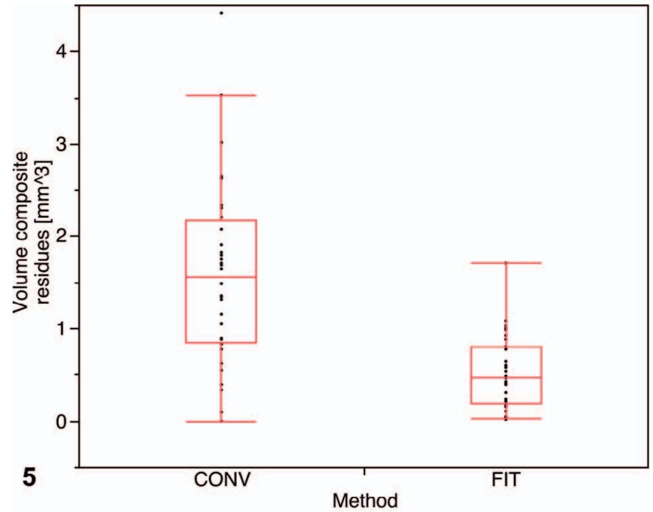


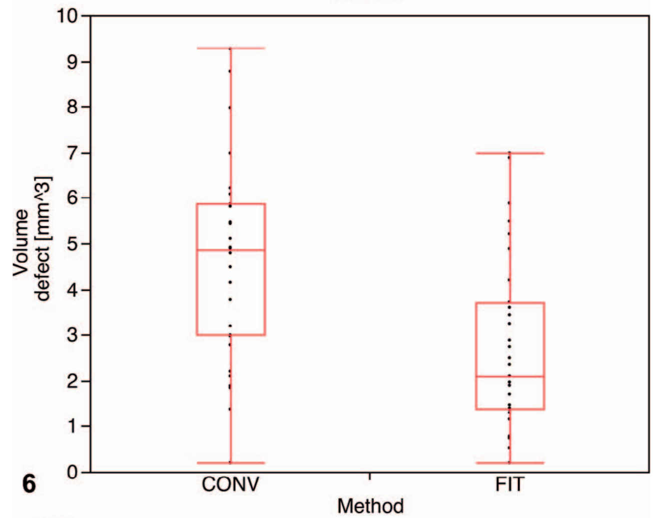
Figure 4. *Preoperative (PreOP) and postoperative (PostOP) images of the volumetric assessment of a premolar with the conventional technique (CONV, left) and with FIT (right).*

The mean volume of composite residue was 1.58 mm^3 (SD 0.99 mm^3; 95% CI: 1.23-1.94 mm^3) for the conventional technique and 0.53 mm^3 (SD: 0.39 mm^3; 95% CI: 0.39-0.67 mm^3) for FIT (Figure 5). The mean volume of dental hard tissue defects was 4.53 mm^3 (SD: 2.12 mm^3; 95% CI: 3.77-5.30 mm^3) for the conventional technique and 2.77 mm^3 (SD: 1.83 mm^3; 2.11-3.43 mm^3) for FIT (Figure 6). The mean duration of the removal procedure per restoration for was 329 seconds (SD: 169 seconds; 95% CI: 268-390 seconds) for the conventional technique and 179 seconds (SD: 80 seconds; 95% CI: 150-208 seconds) for FIT (Figure 7). Table 1 lists detailed results (overall and per operator) regarding volume of composite residue, maximum height of composite residue, percentage of composite removal, volume of defect, maximum depth of defect, and time.

DISCUSSION

The present *in vitro* study compared conventional composite removal with a fluorescence-aided approach. The results showed that FIT improved the selectivity of composite removal and resulted in fewer defects in the adjacent dental hard tissue.





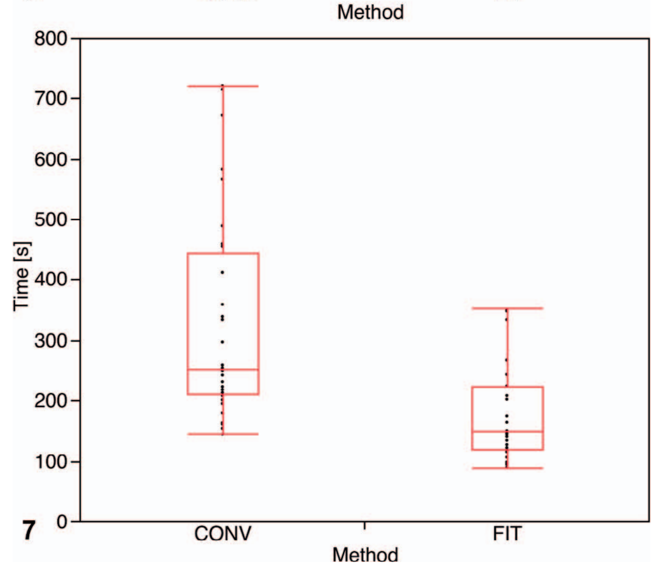


Figure 5. *Box plots of the volume of the composite residues (mm^3) for the conventional technique (CONV) and FIT.*
Figure 6. *Box plots of the volume of dental hard tissue defects (mm^3) for the conventional technique (CONV) and FIT.*
Figure 7. *Box plots of the treatment duration (seconds) per restoration for the conventional technique (CONV) and FIT.*

Table 1: *Mean Results (SD, 95% CI) Regarding Composite Residues (Volume, Height, and Percentage of Removal), Defect Volume and Depth, and Duration*[a]

Operator and Technique	Volume Composite Residue (mm^3)	Maximum Height Composite Residue (mm)	Percentage of Composite Removal (%)
Operator 1: conventional technique	1.18 (0.74; 0.79-1.58) B,C	0.72 (0.46; 0.47-0.96) A	92.99 (3.90; 90.92-95.07) B,C
Operator 1: FIT	0.37 (0.32; 0.20-0.54) D	0.23 (0.14; 0.16-0.30) B	97.82 (1.79; 96.87-98.78) A
Operator 2: conventional technique	1.99 (1.07; 1.41-2.56) A	1.05 (0.58; 0.74-1.36) A	88.12 (6.47; 84.67-91.56) D
Operator 2: FIT	0.68 (0.40; 0.47-0.90) C,D	0.24 (0.14; 0.17-0.31) B	95.93 (2.76; 94.46-97.40) A,B
Overall: conventional technique	1.58 (0.99; 1.23-1.94) A,B	0.88 (0.54; 0.69-1.08) A	90.55 (5.81; 88.46-92.65) C,D
Overall: FIT	0.53 (0.39; 0.39-0.67) D	0.24 (0.13; 0.19-0.28) B	96.88 (2.48; 95.83-97.77) A

[a] Tukey test: significant differences within each column are indicated by different superscript letters.

Furthermore, composite removal with FIT was less time-consuming than conventional composite removal procedures.

FIT makes use of illuminant metamerism, which describes the perceived color match of two materials with different spectral power distributions under certain illumination conditions but not under others.[10,15,23] The fluorescent behavior of the majority of composites is distinct from that of dental hard tissues.[16,24] Thus, the use of illumination sources with wavelengths in the range of 405 ± 10 nm makes it easy to visually distinguish between tooth substance and color-matched metameric composites.[15] FIT allows to quickly and accurately detect tooth-colored composite restorations.[15] Moreover, FIT facilitates the removal of trauma splints and orthodontic brackets, minimizing the risk of iatrogenic damage to the enamel.[17,19] Other approaches for the selective removal of composite have been described. For example, carbon dioxide lasers guided by spectral feedback render a high level of ablation selectivity possible for composites.[14] However, compared with laser-based ablation techniques, FIT may be more readily implementable in clinical practice as it is suited for intraoral examinations and restorative procedures alike, and it only requires an illumination source with a light spectrum in the of range of 405 ± 10 nm.[15,24] When using FIT, it is important to follow the safety instructions of the LED manufacturer and to use adequate eye protection such as safety glasses with filter lenses to avoid potentially detrimental health effects of blue-violet and ultraviolet light.

The direct restorations in the present study were placed with a nanohybrid direct composite material that has strong fluorescent properties.[16] Clinical studies report only minor differences in the clinical behavior of direct restorations placed with different composite materials.[2] Although some filler characteristics may have an impact on late failings of composite restorations,[25] the physical properties of available composites are considered to be of subordinate significance for restoration longevity.[2,26] When placing direct restorations in posterior teeth, it may therefore be advantageous to choose metameric composites that have a documented good performance in clinical trials plus strong fluorescent properties.[16,24] The latter may facilitate repair or replacement in the restorative cycle provided that FIT is used.

The replacement of restorations continues to be a common clinical procedure, imposing a heavy burden on health care expenditure across the globe.[1,4,27] Fractures and secondary caries are the main reasons for the failure of direct composite restorations in posterior teeth.[2,3] Prevention and control of secondary caries are therefore of paramount importance: patient-related risk factors should be appropriately managed and materials selection and restorative procedures have to be carried out with due diligence and care.[1,12] Furthermore, current detection methods for secondary caries lesions are best used in combination, not on their own, at specific thresholds to avoid false-positive diagnoses.[28] In addition, contemporary caries excavation techniques such as selective caries removal, which frequently have distinctive radiographic features, should be taken into account to avert invasive and costly overtreatment and ensure the best patient-centered outcome.[29]

The advantages of restoration refurbishment and repair over replacement are legion: most importantly, the lifespan of a partially defective restoration can often be prolonged through refurbishment or repair.[8,13,30] When a restoration is replaced, some sound tooth structure is inevitably removed and the cavity is frequently enlarged.[11-13] Therefore, the possibilities of restoration refurbishment and repair need to be exhausted. Replacement restorations should be deemed indicated only when, based on a

Table 1: *Mean Results (SD, 95% CI) Regarding Composite Residues (Volume, Height, and Percentage of Removal), Defect Volume and Depth, and Duration (ext.)*

Operator and Technique	Volume Defect (mm^3)	Maximum Depth Defect (mm)	Time (s)
Operator 1: conventional technique	5.77 (1.89; 4.77-6.78) D	0.99 (0.18; 0.89-1.08) B	328.50 (168.78; 238.56-418.44) A,B
Operator 1: FIT	3.73 (1.83; 2.76-4.71) B,C	0.58 (0.18; 0.48-0.67) A	163.19 (69.79; 126.00-200.37) C
Operator 2: conventional technique	3.29 (1.56; 2.46-4.12) A,B,C	0.90 (0.32; 0.73-1.70) B	329.06 (174.75; 235.94-422.18) A,B
Operator 2: FIT	1.80 (1.24; 1.14-2.47) A	0.44 (0.16; 0.35-0.52) A	195.13 (88.99; 147.71-242.54) B,C
Overall: conventional technique	4.53 (2.12; 3.77-5.30) C,D	0.94 (0.26; 0.85-1.04) B	328.78 (169.00; 267.85-389.71) A
Overall: FIT	2.77 (1.83; 2.11-3.43) A,B	0.51 (0.18; 0.44-0.57) A	179.16 (80.32; 150.20-208.11) C

meticulous assessment, the possibility of refurbishment or repair has been ruled out.[30-32] The results of the present study suggest that FIT makes it easier to selectively remove composite and contributes to the preservation of sound dental hard tissue. Thus, FIT may be a useful tool for the repair and replacement of composite restorations.

The operators in the present study aimed at removing composite as completely as possible. In clinical settings, however, the replacement of defective composite restorations does not necessarily require the complete removal of old composite. For instance, it may frequently be advisable to leave composite near the pulp chamber to reduce pulp irritation.[33] Adequate bond strengths between the composite of the old restoration and new composite are obtainable when mechanical and adhesive surface pretreatments are performed.[9,34,35] The application of appropriate repair techniques obviates the need for complete composite removal, and FIT may facilitate to deliberately leave composite close to the pulp.

To determine the appropriate pretreatment and bonding protocols, one must know whether a cavity is bounded by composite or dental hard tissues or both.[6] Composite detection with FIT is straightforward and swift.[15] Therefore, FIT used for cavity inspection seems to be a useful aid to select the proper pretreatment method. The present study indicates that composite removal procedures hardly ever achieve the complete removal of restoration material. When replacing direct composite restorations, airborne particle abrasion with aluminum oxide may, consequently, be recommended as cavity pretreatment in most cases.

The present study has certain inherent limitations that demand careful consideration. First, the direct composite restorations had no visible defects or imperfections whatsoever, and spectrophotometric shade selection ensured an exact color match. In contrast, restorations that are replaced in clinical practice are usually (partially) defective.[30] Common features of intraoral aging such as marginal staining may facilitate the removal procedure. The present study simulated challenging conditions, and therefore its results may not directly translate to clinical settings where composite removal is straightforward owing to substantial defects and/or conspicuous color differences. However, in the setup of the present study, patient-related factors that can complicate restorative interventions (limited mouth opening and suchlike) were absent. Arguably, composite removal procedures in clinical settings frequently present an even bigger challenge than in the present study.

Second, in the present study a custom micromotor that emitted blue light at a wavelength of 405 nm through the illumination source of the handpiece was used in the FIT group. This allowed the fluorescence-aided detection of composite while the handpiece was in use. Such a setup offers a seamless workflow and hence time savings.[19] However, currently there are no micromotors or handpieces with integrated FIT commercially available. There are some devices on the market that emit light with the wavelengths required for FIT (eg, D-Light Pro, GC Corporation, Tokyo, Japan; SiroInspect, Dentsply Sirona). When one uses such devices for composite removal procedures, fluorescence-aided detection and composite removal usually occur in separate steps. As a consequence, removal procedures using FIT in this manner may be slightly less expeditious than in the present study. Further research is needed to assess what impact the use of currently available equipment has on the treatment duration of fluorescence aided composite removal.

Third, a couple of young dentists with unimpaired eyesight performed the composite removal procedures in the present study. The completeness and selectivity of composite removal are, to a degree, dependent on the operator.[19] In addition, near visual acuity under simulated clinical conditions varies between individuals and decreases with advancing age.[36] In the present study, the small convenience sample of operators was biased toward young dental professionals. It would therefore be desirable that subsequent investigations are undertaken with a more representative sample of dentists to evaluate the replicability of the present study.

CONCLUSIONS

Within the limitations of this *in vitro* study, FIT improved the selectivity and completeness of composite removal, and composite removal procedures using FIT were more expeditious compared with the conventional technique. FIT may thus contribute to tooth substance preservation when the repair or replacement of defective direct composite restorations is indicated.

Acknowledgements

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Regulatory Statement

This study was conducted in accordance with all the provisions of the local human subjects oversight committee guidelines and policies of the Ethikkommission Nordwest- und Zentralschweiz. The approval code for this study is EKNZ UBE-15/111.

Conflict of Interest

The authors of this manuscript certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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