Quantifying composite restoration removal and cavity re-preparation using novel region-specific volumetric analysis

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Abstract

Objectives

This in-vitro study investigated the effect of 400-405nm light used during removal of a composite restorations on volume of tooth tissue removed iatrogenically (IATR) and the volume of residual composite.

Methods

Thirty unrestored premolar teeth obtained via a university tissue bank were evenly allocated to test and control groups; material removal with and without violet light. Three clinicians (blinded to the protocol) prepared class V buccal cavities in the teeth. The teeth were scanned using CEREC Omnicam and reallocated to another clinician prior to restoration and rescanning. The teeth were reallocated, and the restorations were removed prior to rescanning.

Volumetric scan data was obtained on: changes in cavity volume; the volume of IATR; the volume of residual composite. Data were analysed using Shapiro-Wilk and Kruskal–Wallis tests to a significance of $p<0.05$.

Results

Data showed that there is more IATR when the light was used with mean volume CAV2-over cut of (3.4 mm3, SD 4.22) whereas less IATR was seen when the light was not used (1.2 mm3, SD 1.00), ($p<0.05$). Data also showed that there is no significant difference in the overall volume of resin composite left when the light was used or not ($p> 0.05$). However when the light was used, less resin composite material was left around the margins of the cavities when compared to the no light group.

Significance

This novel region-specific cavity analysis method reveals patterns of iatrogenic damage and retained composite which may hold clinical relevance. The use of violet light may result in more complete removal of composite at margins, but also increase IATR. Further research using the novel method is required to ascertain the repeatability and clinical significance of findings.

Key Words

Resin Composite

3D imaging

Composite removal

1. Introduction

Dental composite materials are widely used in restorative dentistry with increasing popularity due to the declining use of amalgam and comparative advantages of composite, such as pleasing aesthetic properties and preservation of tooth tissue.[1] However, despite their popularity, dental composite materials also possess some notable disadvantages, one of which relates to difficulty in removing the restorative material completely whilst minimising iatrogenic tooth removal. This has been well documented[2–4], with removal of composite restorative material resulting in significantly greater enlargement of cavities compared to amalgam.[5] Additionally, it is reported that 27% of cavities may inadvertently contain residual composite.[6] There have been many techniques suggested to overcome this handling challenge. These include etching the tooth surface causing in a visual change in the appearance of enamel and dentine, laser ablation to modify the surface texture of resin composite[7], the use of various dyes[8], and visual examination for marginal defects under high magnification.[4] All of these techniques are time consuming and technically sensitive. Recently, it has been suggested that the fluorescence of resin composite under violet light may help in distinguishing this material from enamel and dentine.[9,10]

There is a dearth of research evidence to demonstrate the impact violet light when used to aid visualization when removing composite restorative material. Previous studies [6,10–14] have investigated the effect of various light sources for this role. The majority of studies focus on ultraviolet light for this purpose, whilst violet light may be more readily available in the form of commercial light curing units.[15] A recent example is the “D-LightPro” (GC Corporation, Tokyo, Japan), which is a third generation LED light with two curing modes high power (1400mW/cm2) and low power (700mW/cm2) modes. It also offers a unique “Detection Mode” based solely on violet light LED with spectrum raining between 400-405nm. This violet light facilitates identification of infected dentine, plaque, micro-leakage, and fluorescent restorations such as resin composites by utilizing the fluorescent properties of different materials.

The majority of published literature focusses on the removal of composite from the surface of enamel; mimicking resin removal following orthodontic debond.[6,14] These findings are therefore not directly comparable to the removal of resin composite which has been utilized to restore caries due to differences in aesthetic, tactile feedback, and the presence of altered tooth anatomy within a three-dimensional cavity. There are few studies investigating *volumetric* changes in cavity size when using violet light as a visual aid or comparing effective composite removal in conjunction with iatrogenic tooth removal.[6,14] One study has recently investigated the impact of fluorescence on composite removal by using a digital process.[16] Whilst this method offers the opportunity to more accurately assess the volume of composite retained and the volume of iatrogenic tooth removal, the described study performed on alternative outcome variables such as cavity width and time taken to complete restoration removal. Additionally, this study utilised white light illumination rather than 400-405nm light.

There has been no research investigating *regions* of the cavity where there is iatrogenic tooth removal or incomplete material removal. This is important because the location of any excess tooth removal, or remnants of composite, is clinically relevant to the potential success of the new restoration. [4] For example, composite remnants left at the periphery of the cavity will affect the bond, and peripheral seal, of the new restoration in this critical area. Hence, a small amount of excess tooth removal at the periphery of the cavity might be desirable. Conversely, excess tooth removal deep inside the cavity may risk adverse pulpal sequelae, and it might be argued that a small amount of composite left *in situ* would be preferable. However, to understand the scale of these issues, a region-based volumetric analysis is required for each cavity re-preparation, rather than a standard volumetric, or surface deviation method.

This study presents a novel region-based three-dimensional (3D) volumetric analysis method for assessing cavity re-preparation. It uses this method to explore the effect of the use of a violet light during composite removal.

1.1. Study aims and hypothesis

Null hypothesis:

(1) No significant difference in iatrogenic damage when removing composite restorations, as defined by conventional volumetric analysis vs novel region-specific 3D volumetric analysis

(2) No significant difference in iatrogenic damage as defined by either of the above methods when using a violet light vs. no light

2. Materials and Method

2.1 Teeth selection and cavity preparation

Thirty unrestored human premolar teeth were obtained via a university tissue bank in compliance with the Human Tissue Act (approval code 231018/JP/260). These were randomly assigned to treatment/clinician groups as outlined in table 1. All unprepared teeth were 3D scanned using a CEREC Omnicam (Dentsply-Sirona, Charlotte, USA) running software version 4.6 to provide baseline pre-operative data (PRE). Each tooth was prepared for a buccal class V cavity. Each clinician prepared all teeth within the allocated group with a class V buccal cavity 2mm coronal to the CEJ using a standardised round coarse diamond bur (ISO 001).

2.2 3D scanning and analysis of the Class V Cavities

All prepared Class V cavities were re-scanned and aligned to the pre-operative scan using WearCompare.[17] A cropping region lasso was identified on each individual tooth, to encompass the full cavity outline plus an additional 1mm margin. This custom region was used to create two volumetric blocks representing a chunk of the pre-operative tooth (PRE), and the cavity and a region of tooth around the cavity (CAV1). These blocks were saved as STL files, along with the cropping region lasso. This process is illustrated in the top row of figure 1. The colour mapped images in figure 1 were produced in WearCompare and give a qualitative illustration of volume changes. However, it is important to note that all *quantitative data* was derived from an image stack analysis method as outlined below, using the volume blocks exported from WearCompare. The exported STL files were voxelised by creating image stacks (voxel size 25 microns) using custom software written with OpenCV.[18] Mean initial cavity volume was calculated using a per-voxel analysis over all pairs of corresponding images in the stacks (PRE and CAV1), such that voxels which were 'tooth' in PRE, but 'air' in CAV1, were deemed part of the initial cavity (figure 2).

2.3 Resin composite restorations

Following initial cavity scanning, the newly assigned clinician for each group restored the buccal cavities with Filtek Supreme XTE Universal (3M ESPE, Minnesota, USA) resin composite. Care was taken to optimise the restoration quality and aesthetics using best practice principles including composite layering and polishing. This aimed to optimise shade, translucency, surface polish as well as primary and secondary anatomy. This included the use of FGB700 37% phosphoric acid etchant (Unodent Ltd, Witham, England) and dentine bonding agent (Optibond Solo Plus, Kerr) as per manufacturer instructions. Composite restorations were light cured for 20 seconds following application of dentine bonding agent and 40 seconds following each increment of the composite restorative material using (GC Corporation, Tokyo, Japan) with irradiance of 1400mW/cm^2 using D-Light Pro (GC Corporation, Tokyo, Japan) in a "high performance" mode.

2.4 Removal of Resin composite restorations

Two groups of restored teeth were allocated to each clinician (Table 1): Group 1 restorations to be removed without use of violet light and Group 2 restorations to be removed with aid of violet light. Restorations were removed using a standardised round coarse high speed diamond bur (ISO 001) with water. The violet light was used as per the manufacturers instructions with the hard light protector in-situ

Clinicians were made aware of each task immediately prior to each activity to ensure blinding throughout stages where possible. The aim of the study was only made clear following completion of all tasks.

All three clinicians worked within the a teaching hospital as training grade clinicians. Equipment utilised on a routine clinical basis was made available to optimise each step.

The teeth were subsequently analysed following composite resin removal. Second cavity volume (CAV2) was measured and the change in cavity volume compared to CAV1 was measured using conventional subtraction method (CAV2–CAV1). Further cavity analysis was conducted using region based volumetric analysis method whereby the below variables were measured to identify the changes within CAV2:

Second cavity volume overcut (CAV2-over cut), this was considered as iatrogenic damage (IATR)

Resin composite left within the cavity (RC-CAV)

Resin composite at the margins (RC-MAR)

2.5 Scanning and analysis of teeth following restoration removal

All premolars were subsequently 3D scanned and aligned to their CAV1 counterparts as previously described (CAV2). Matched volumetric segments were exported as STL files from WearCompare, using the same bespoke cropping lasso as had previously been used for the PRE and CAV1 volumes. Image stacks were created for the CAV2 volumes, and a per-voxel 3-way analysis of PRE-CAV1-CAV2 was performed allowing identification in CAV2 of multiple regions of interest as follows; composite retained at margin ('air' in PRE, 'solid' in CAV2), composite retained in cavity ('cavity' in CAV1, 'solid' in CAV2), iatrogenic damage ('tooth' in CAV1, 'air' in CAV2). In addition, the standard coarser measure of whole cavity volume was calculated for CAV2, enabling naïve volume change comparison against CAV1.

2.6 Statistical analysis

Statistical analysis was conducted using IBM SPSS 25. Data was analysed for normality using Shapiro-Wilk Test and comparisons were made using Kruskal–Wallis test with post hoc Bonferroni with a significance level of $p<0.05$.

3. Results

Two teeth were excluded due to an error in incorrect operator allocation, leaving 28 teeth in the experiment. The overall mean initial cavity volume for the teeth allocated to the light group was (6.24 mm^3, SD 3.71) and no light group (6.36 mm^3, 3.63SD), this was not statistically significant ($p > 0.05$).

Using the conventional method of assessment of the overall volume of CAV1 and CAV2 for the combined groups (light and no light), showed no statistically significant change in the size of the cavities ($p>0.05$); the overall mean volume of CAV1 was (6.03 mm^3, SD 3.60) which was comparable to CAV2 (6.55 mm^3, SD 4.02) with a mean difference (CAV2-CAV1) of (0.25 mm^3, SD 4.60), figure 3(A).

This change in cavity volume was also not found to be different whether the light was used or not for preparation of CAV2; the mean change in cavity volume when the light was used was (1.11 mm^3, SD 6.05) and (0.60 mm^3, SD 2.38) with no light, ($p>0.05$), figure 3(B).

However further analysis of CAV2 using the novel region-specific 3D volumetric analysis facilitated exploration of the nature of preparation errors (CAV2-over cut), this was considered as iatrogenic damage (IATR), graphical example is shown in figure 4.

Data showed that teeth were overcut by a mean of (2.33 mm^3, SD 3.02) when compared to CAV1. This was shown to be statistically significant when compared to the mean difference in cavity volume (CAV2-CAV1) previously measured using the conventional subtraction method, ($p<0.05$), figure 3(C). Analysis using this novel method also showed significant differences between the light and no light groups. The mean volume CAV2-over cut when using the light was (3.4 $mm^{3,}$ SD 4.22) whereas this was significantly less when the light was *not* used (1.2 mm^3, SD 1.00), ($p<0.05$), figure 3(D).

Furthermore, the amount of resin composite volume left within CAV2 was analysed, (Table 2). Data showed that there is no statistically significant difference in the overall volume of resin composite left in CAV2 when the light was used or not. Further analysis of the resin composite left within CAV2 showed that when the light was used, less resin composite material was left around the margins of the cavities when compared to the no light group, however this was not found to be statistically significant ($p>0.05$). Graphical examples of composite remaining at the margin, cavity overcut and composite remaining at the margin are shown in figure 5.

Data showed that inter-operator variation was found in the overall volume of composite left within CAV2 (RC-Vol) and amount of resin composite left at the margins (RC-Vol-Margin), however this was not statistically analysed due to the small sample size per operator, figure 6 (A and B).

4. Discussion

This study presented a novel technique for region-specific 3D analysis of volume change over time. The technique uses freely available and open-source software, making it readily accessible to all researchers. The study investigated the effect of using this technique, compared to conventional volumetric analysis. The method was then applied to a typical use-case, namely the removal and replacement of composite restorations. The latter was studied in relation to the effect of the use of a violet detection light during composite removal.

The novel technique was compared to naïve (standard) volumetric analysis in the context of composite removal and cavity repreparation. It was shown that the standard analysis method revealed no significant difference between the sizes of the original cavities and the sizes of the re-prepared cavities. This would lead to the conclusion that removal of composite restorations did not cause additional iatrogenic damage. By contrast, when using the region-specific analysis, it was shown that more tooth structure was removed during the cavity re-preparation, and thus some degree of iatrogenic damage occurred. These changes in *tooth* volume were significant compared to the conventional volumetric analysis ($p<0.05$, figure 3 (C)), and describe the iatrogenic damage more clearly. The first null hypothesis must therefore be partially rejected, for the case of the region-specific analysis.

The clinical relevance is heightened further when one considers that the reason the conventional comparison method failed is that the re-prepared cavities consisted of both excessively removed tooth structure and retained composite. The combined effect of this presumably resulted in minimal overall changes in cavity volume, but the clinical outcome may be reduced bonding (particularly if composite is retained around the margin of the cavity) and unsuspected pulpal sequelae (due to excess tooth removal and decreased bonding). The region-specific analysis painted a clearer picture of the clinical situation and should be recommended.

The second part of this study employed the novel analysis technique to assess the effect of using a detection light during composite removal and cavity repreparation. Effective removal of composite restorative material whilst minimising iatrogenic tooth removal can be challenging. Whilst tools to improve visualisation during removal of material have been suggested in the literature, the present pilot study suggests complex interactions between the use of an LED violet light visual aid, complete composite removal and iatrogenic damage. Additionally, the findings from this study suggest this may be technique sensitive, resulting in inter-clinician variability.

Whilst the use of an LED violet light appears to be effective in detecting resin composite restorations within the natural tooth by utilising the optical properties of the material, the clinical utility of this may be dependent on the region within the cavity that it is used for. Data obtained suggest a trend towards more complete removal of composite material with the use of violet light, particularly at the restoration margins. Nonetheless, data also show a statistically significant difference in iatrogenic damage with and without the use of an LED violet light, suggesting that use of violet light may be associated with a higher false positive rate in detecting residual restorative material (ie the use of the light led to a more complete removal of old composite, but at the expense of increased healthy tooth removal). It is not clear if this is associated with the size or morphology of the restoration. Further research is required to determine the diagnostic accuracy of restoration detection when using an LED violet light.

The present study highlights the value of 3-dimensional analysis of cavity volumes to enrich the dataset and provide further insight into the effects of visual aids on the removal of composite restorative material; whilst differences in surface area (described in previously published literature)[9,10,13,14] are of clinical relevance, the location of residual composite (i.e. at the cavity margin or base) as well as the relative location and volume of iatrogenic damage are more critical to the success of replacement restorations as well as the tooth in question. This study highlighted that relying solely on comparing the initial cavity volume (CAV1) to the second cavity volume (CAV2) following preparation may provide misleading description of the changes within the cavity. Initial assessments of the differences between the cavity volumes (CAV1) and (CAV2) with and without the use of light showed no statistically significant differences, ($p>0.05$) as shown in figure 3 (B). Further analysis of the prepared cavities (CAV2) showed that cavities were in fact overcut beyond the margins of the initial cavity preparation (CAV1) and significant differences were found between the light and no lights groups ($p<0.05$); this was defined as CAV2-overcut described in figure 3 (D). The second null hypothesis must be partially rejected, for the case of region-specific analysis.

This method also provides valuable information as it allows quantifying the iatrogenic damage caused. Furthermore, the analysis method used in this study allowed evaluation of the resin composite volume left within CAV2. This was shown to provide beneficial information in relation to the amount of resin composite left within the cavity and around the margins. Exploratory analyses suggest that less resin composite material was left at the margins of the cavities when the light was used compared to the no light group as shown in Table 2. However, no statistical significance was found within these trends although this is probably due to the smaller number of samples in this pilot study.

It is difficult to achieve a reliable bond to aged composite resin due to the diminished availability of unsaturated bonds within the material over time.[19,20] Residual material at the margins is therefore undesirable.

Restoration failures often occur at the cavity margins resulting in microleakage.[21,22] Consequently, incomplete removal of the old resin composite restoration at the cavity margins may impact on the marginal seal and longevity of the restoration.

These results might point towards a clinical recommendation that a violet light should be used judiciously during composite removal, with the operator paying particular attention to removing composite highlighted at the cavity margins, while simultaneously ignoring regions highlighted deeper within the cavity. Further studies with a larger sample are needed to validate or refute this recommendation.

Finally, the data obtained suggest notable variation between clinicians, which may be the result of clinician specific factors, or initial cavity characteristics such as volume and morphology. Further investigation of these factors will provide insight into the factors influencing the effectiveness of visual aids in the removal of composite restorative material.

5. Conclusion

The use of a novel region-specific volumetric analysis when assessing composite removal and re-preparation yielded significant, and clinically relevant differences compared to standard volumetric analysis. Iatrogenic damage was clearly highlighted using the novel technique but masked when using the standard technique.

With the novel analysis technique, the use of violet light as a visual aid when removing composite restoration material resulted in a larger volume of iatrogenic tooth removal and more inadvertent retention of previous composite compared to when violet light is not used.

Further work is required to characterise these associations for different cavity types and different composite materials.

Funding

Funding was not required for this study.

Conflict of Interest

None.

6. References

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Tables

Group number	Initial cavity preparation (CAV1)	Cavity restoration with resin composite	Second cavity preparation (CAV2)	Light used for second cavity preparation
1	Operator H	Operator T	Operator M	Yes
2	Operator H	Operator T	Operator M	No
3	Operator M	Operator H	Operator T	Yes
4	Operator M	Operator H	Operator T	No
5	Operator T	Operator M	Operator H	Yes
6	Operator T	Operator M	Operator H	No

Table 1: Operator allocation to initial cavity preparation, cavity restoration with resin composite and second cavity preparation.

Mean volume (mm^3)	With Light	Without Light	Sig.
Overall composite left	2.06	1.26	0.98
Composite left at margins	0.40	0.70	0.10

Table 2: The mean volume of composite left within the cavity after CAV2 preparation, and left at the cavity margin, with and without using the LED light amongst all operators.

List of Figures

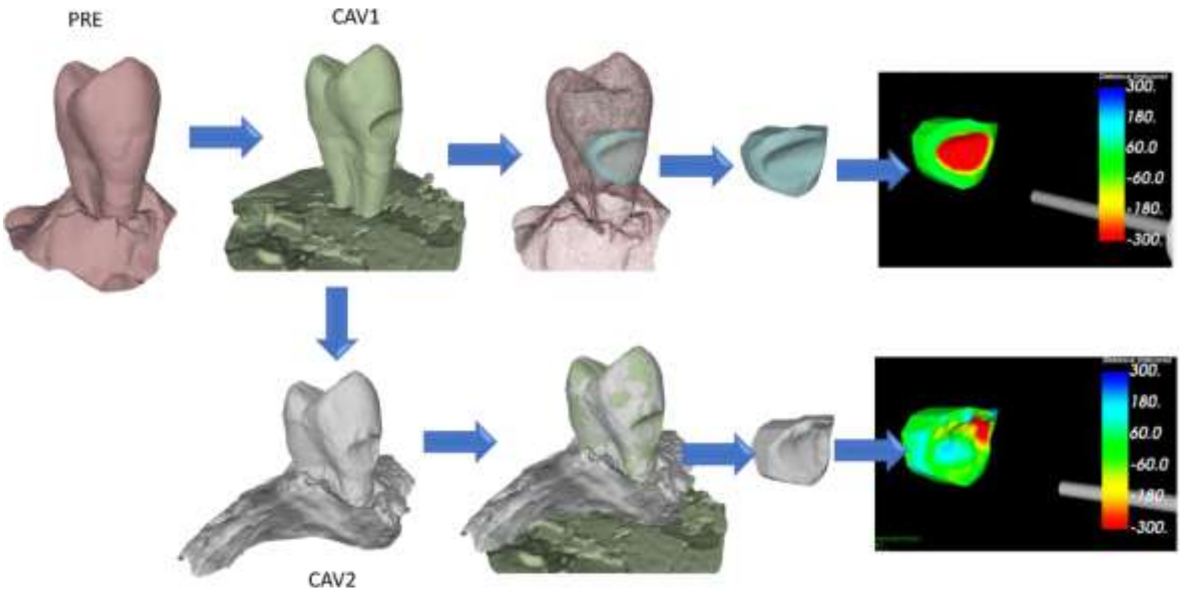

Fig. 1. Outline of method. An unprepared tooth (PRE) is scanned, prepared (CAV1) and re-scanned. A volumetric tile is created in WearCompare and converted into an image stack for per-voxel analysis. The tooth is restored with composite and a different operator re-prepares the cavity (CAV2). A comparison of CAV1 and CAV2 is performed using volumetric tiles created by WearCompare, and per-voxel image stack analysis to precisely identify areas of remaining composite and areas of iatrogenic damage (image stacks not shown).

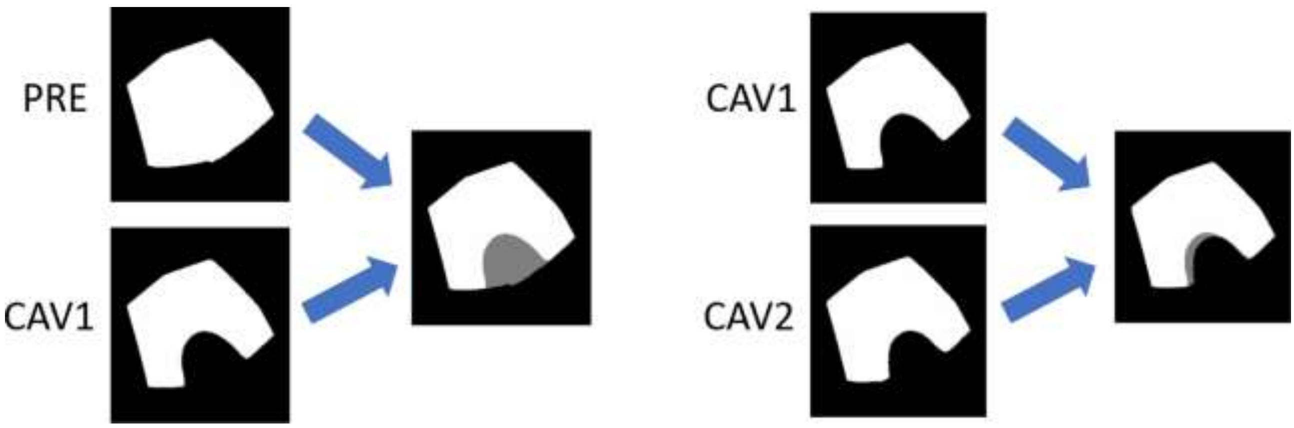

Fig. 2. Image stack analysis. Examples of a single slice (resolution 25 µm) through the aligned blocks exported from WearCompare, of the unprepared cavity (PRE), the initial cavity (CAV1) and the reprepared cavity (CAV2). Combining the stacks enabled identification of multiple regions, such as 'initial cavity

volume' (left, in grey) and 'composite remaining in cavity' (right, in grey). Other regions used in this study were 'cavity overcut' and 'composite remaining at margin' (not shown).

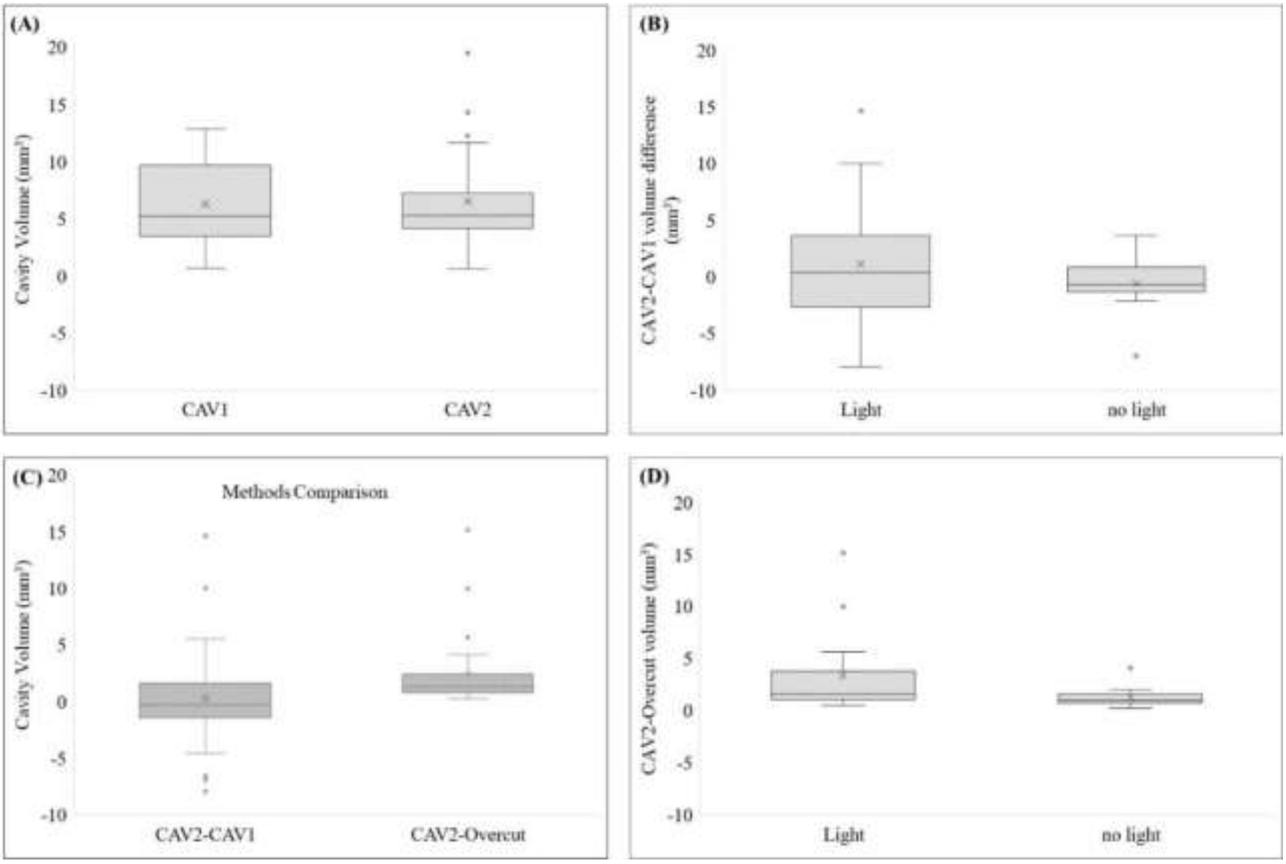

Fig. 3. (A, B) show cavity volume analysis using the conventional subtraction method which showed no statistically significant difference in the change in the size of the cavities, either overall (A) or when comparing the use of the light (B) ($p>0.05$). (C) shows comparisons between the conventional method measuring the mean cavity volume change (CAV2 – CAV1) vs 3-dimensional region-based analysis exploring the nature of preparation errors by measuring (CAV2-over cut). (D) shows the significant effect on CAV2-Overcut when using the light, under the novel region-based analysis method ($p<0.05$).

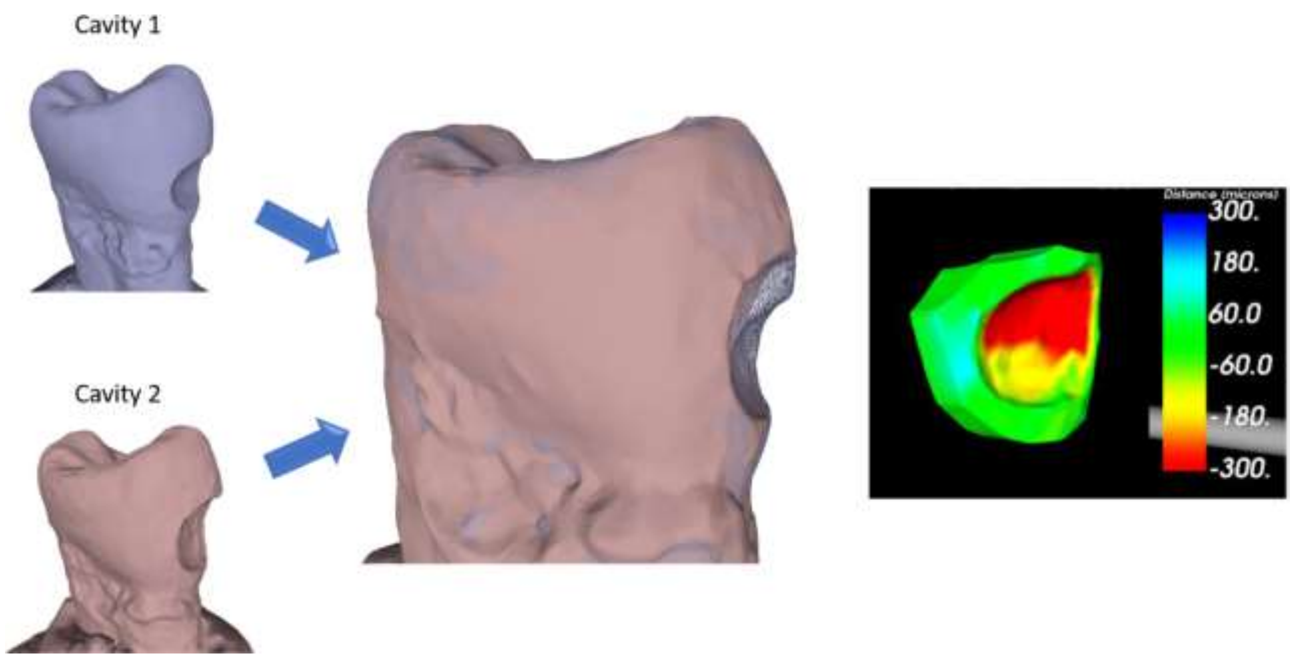

Fig. 4. Example of an overcut cavity. The region in the upper part of the cavity was overcut, as is visible in the volumetric tile created by WearCompare.

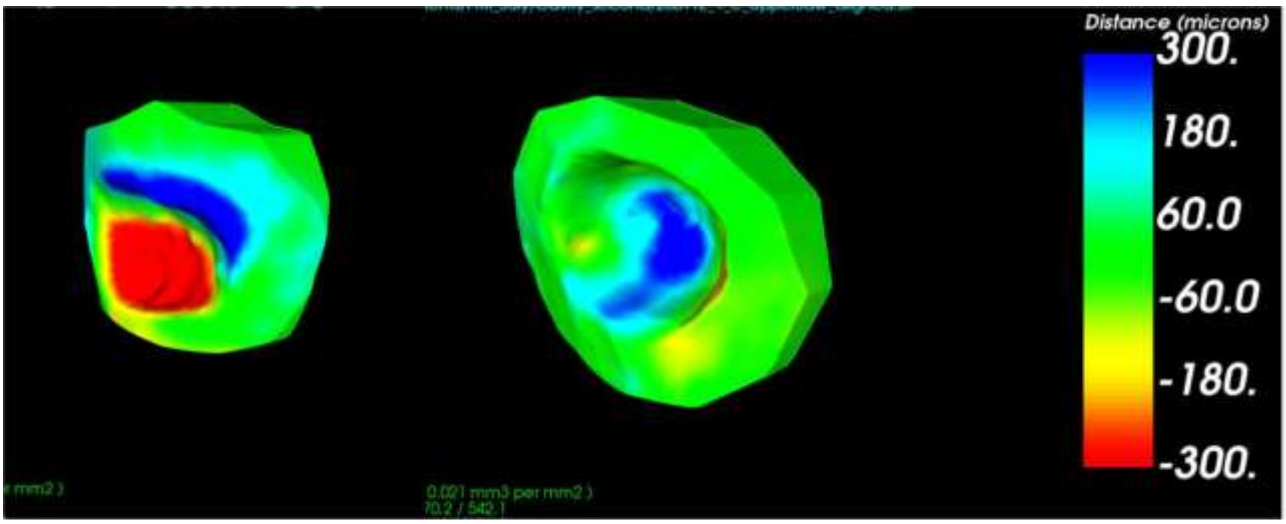

Fig. 5. Colour map examples. Left image shows a cavity which was overcut internally (red), but with composite remaining at the margin (blue). Right image shows composite remaining within the cavity (blue). The volumetric per-slice analysis (not shown) enabled precise quantification of all of these regions.

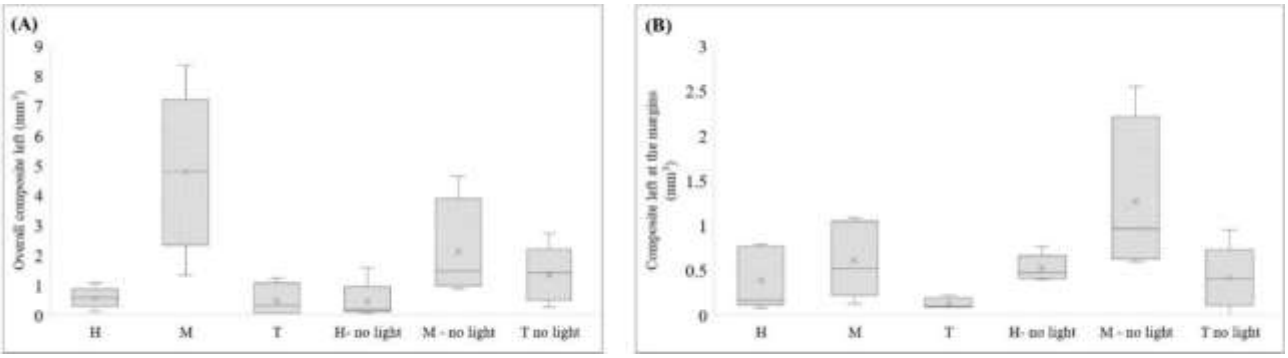

Fig. 6. (A) The mean volume of the overall composite left within the cavity. (B) The mean volume of the composite left at the margins of the cavity.