Effect of ultrasonic vibration on the presence of voids in core build-up materials

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The core build-up procedure is utilized to restore teeth with limited remaining coronal tooth structure. However, voids have been observed radiographically within composite resin– and glass ionomer–based core build-ups, potentially compromising the mechanical strength of a fully restored tooth and requiring build-up replacement before a final restoration can be delivered. The purpose of this in vitro study was to determine whether applying ultrasonic vibration during core build-up placement reduces the presence of radiographically detectable voids. A total of 120 acrylic resin mandibular premolar analogs were fabricated using a 3-dimensional printer and randomly allocated into 4 groups (n = 30). Dual-cured composite resin or glass ionomer core build-ups were placed with or without vibration. The final build-ups were assessed radiographically and rated by 3 independent calibrated clinicians based on a 4-category scale for the severity of voids. In an ordinal logistic regression model with the void severity rating as the outcome, a significant interaction was found for glass ionomer, composite resin, and the use of ultrasonic vibration ($P = 0.03$). Vibration was associated with worse void severity ratings in glass ionomer specimens ($P < 0.01$). No effect of vibration was found in the composite resin specimens. The Fleiss kappa score ($\kappa = 0.36$) indicated fair agreement in all severity ratings among the 3 raters. These results suggest that the application of ultrasonic vibration during core build-up placement may not be clinically advantageous for improving restorative outcomes.

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Major changes in teeth after treatment with endodontic therapy include the loss of tooth structure and possible discoloration. Caries, fracture, and endodontic access preparation may all contribute to the loss of tooth structure and subsequent changes in tooth biomechanics. The literature reports 20% to 63% and 14% to 44% reductions in tooth integrity following occlusal access and mesio-occlusodistal preparations, respectively.[1,2]

Endodontically treated teeth have a higher risk of crown fracture due to the loss of tooth structure, and their weakened mechanical properties lead to root fracture over time. To maximize the longevity of endodontically treated teeth, restorations should be designed to prevent fracture of the remaining tooth structure, inhibit reinfection of the treated canals, and restore lost tooth structure.[3] Where a significant amount of coronal tooth structure has been compromised due to caries, restorative procedures, and/or endodontic treatment, a full-coverage cuspal crown is usually indicated. To retain the crown, the remaining coronal structure must be prepared accordingly. In many cases, the placement of a post in one of the root canal spaces is required to provide retention of the core material.[4,5]

Several studies have evaluated how different post materials affect the prevalence of root fracture in endodontically treated teeth as well as the failure mode of the post and core restoration.[5-9] Coelho et al concluded that more homogenous stress distribution was observed when glass and carbon fiber posts were utilized, resulting in a lower incidence of root fracture in endodontically treated teeth.[6] They attributed this result to the fact that the glass and carbon fiber posts had physical properties similar to those of dentin, including modulus of elasticity (Young modulus).[6] Another advantage of using fiber posts is their more favorable mode of failure.[5,7] Studies show that the most common complication of fiber posts and cores is debonding from the tooth, which results in microleakage, secondary caries, restoration mobility, and loss of retention. In contrast, teeth restored with cast metal posts and cores usually exhibit catastrophic failures, such as vertical root fracture, leading to a localized periodontal defect and ultimately requiring extraction of the tooth.[8,9]

Core build-ups replace the missing coronal tooth structure, providing the proper retention and resistance form for the final restoration.[3,5] The materials that can be selected for core build-up include metal (amalgam or cast gold), composite resin, glass ionomer, and resin-reinforced glass ionomer. Favorable physical characteristics of a core material include high compressive strength and flexural toughness, dimensional stability in a wet environment, ease of manipulation, rapid setting time, the ability to bond to both the tooth structure and the post, and biocompatible and cariostatic properties. Popular core materials

in clinical use include amalgam, composite resin, cast metal or ceramic, and sometimes glass ionomer.[3,5]

Composite resin–based core materials have gained popularity in recent years. Among their advantages are their ability to bond to both tooth structure and many post materials as well as their ease of manipulation, fast setting, and radiographically translucent or highly opaque formulations.[3] Composite resin cores have strength that is similar to or better than that of amalgam cores for supporting all-ceramic crowns.[10-12] The degree of complete curing of the resin heavily influences the bond strength to dentin.[3] Therefore, the majority of composite resin core materials on the market are dual-cured formulations to facilitate a more complete polymerization, particularly for clinical situations where photoinitiated curing alone may be challenging. This is especially true for deeper core build-up preparations with undercuts.[3]

Glass ionomer and resin-modified glass ionomer cements can be used to restore small build-ups or to fill undercuts in a prepared tooth.[3,5] Their advantages include the ability to chemically bond to tooth structure as well as their purported fluoride-releasing ability, acceptable shade matching, and biocompatibility.[5] However, the low strength and fracture toughness of these materials may contraindicate their use in anterior teeth.[3] For clinical scenarios in which substantial remaining dentin exists, the extent of the core build-up is minimal to moderate (ie, functional cusps will not be replaced), and caries control is indicated, glass ionomer cement can be employed as a core build-up material.[3]

Soares et al found that bulk-fill composite resins can adapt to cavity walls better than conventional incrementally filled composite resins.[13] Kerr Dental developed a special sonic handpiece to be utilized with their bulk-fill composite resin (SonicFill, Kerr).[14] According to the manufacturer, sonication technology has been well studied in bulk-fill composite resin materials and shown to decrease viscosity during delivery as well as possibly enhance adaptation to the cavity preparation.[14] One study showed that sonication decreases the presence of voids compared with the incremental filling technique.[15] However, another study indicated that sonication might increase void formation during composite resin placement, depending on the restorative material used.[16]

Voids have been observed in bulk-fill composite resins and large incrementally filled composite resins. An increased number and size of voids could result in increased water absorption, fracture, and crack propagation, leading to staining, compromised mechanical strength, and decreased wear resistance.[15-17] Porosity appearing in composite resin– and glass ionomer–based materials may be the result of manufacturing and packaging, spaces formed between layers during placement, and tacky handling properties prior to complete setting of the materials.[16,18]

To the authors' knowledge, no published studies have applied an ultrasonic vibration technique to both dual-cured composite resin– and glass ionomer–based core build-up materials. Therefore, the purpose of this in vitro study was to determine the effect of ultrasonic vibration during core build-up material placement on the presence of voids; the effect was measured with a 4-category scale for the severity of void presence as evaluated using plain-film radiographs. The null hypothesis was that there would be no difference in the severity of voids in composite resin– or glass ionomer–based core build-up materials placed with or without ultrasonic vibration.

Methods

This was an in vitro study investigating the effects of different dental restorative material placement techniques on the final radiographic appearance of the restoration. Three independent, calibrated, board-certified clinicians reviewed the radiographs and scored each specimen based on the relative number and sizes of the voids present. Categorical data were analyzed to determine whether there was a statistically significant difference in the radiographic score based on the clinical technique used (ie, with or without ultrasonic vibration during material placement).

An acrylic resin mandibular right quadrant model and ZP151 calcium sulfate hemihydrate removable second premolars were designed and fabricated using a ProJet 7000 3-dimensional (3D) printer (3D Systems) and a ZPrinter 650 3D printer (Z Corporation), respectively. To simulate a clinical premolar build-up preparation following endodontic therapy and loss of tooth structure due to fracture, the removable premolar analog was designed with a missing lingual cusp. An acrylic resin drill stent was fabricated (ProJet 7000 3D printer) for preparing endodontic access, the pulp chamber, and the canal post space, which was prepared to a size 7 (most apical diameter, 1.75 mm). A total of 120 duplicates of the removable premolar analog were fabricated to fit the mandibular quadrant model.

Study design

The 120 premolar analogs were randomly divided by core material and placement technique into 4 groups (n = 30). Half of the 120 prepared tooth analogs received a dual-cured composite resin build-up, and the other half received a glass ionomer cement build-up. The material groups were further subdivided to be restored with either a bulk-fill technique alone (control) or a bulk-fill technique with the addition of 5 seconds of ultrasonic vibration (experimental). The core build-ups in all 4 groups received glass fiber posts.

In the composite resin control group, dual-cured composite resin (Gradia Core, GC America) was placed with a bulk-fill technique as described in the manufacturer's instructions. In the composite resin experimental group, dual-cured composite resin was placed with a bulk-fill technique in accordance with the manufacturer's instructions, with the additional step of 5 seconds of ultrasonic vibration following material placement and before light curing. In the glass ionomer cement control group, glass ionomer cement (Fuji IX, GC America) was placed with a bulk-fill technique as described in the manufacturer's instructions. In the glass ionomer cement experimental group, glass ionomer cement was placed with a bulk-fill technique in accordance with the manufacturer's instructions, with the additional step of 5 seconds of ultrasonic vibration following material placement.

Glass fiber post cementation

Size 7 fiber posts (GC America) were utilized in all tooth analogs. The core materials were placed in the canal space with their respective manufacturer-supplied dispensing tips. A size 7 fiber post was inserted in the canal space of each analog, and the material was cured for 20 seconds with an LED curing light (Elipar S10, 3M; 1200 mW/cm^2, 430- to 480-nm wavelength).

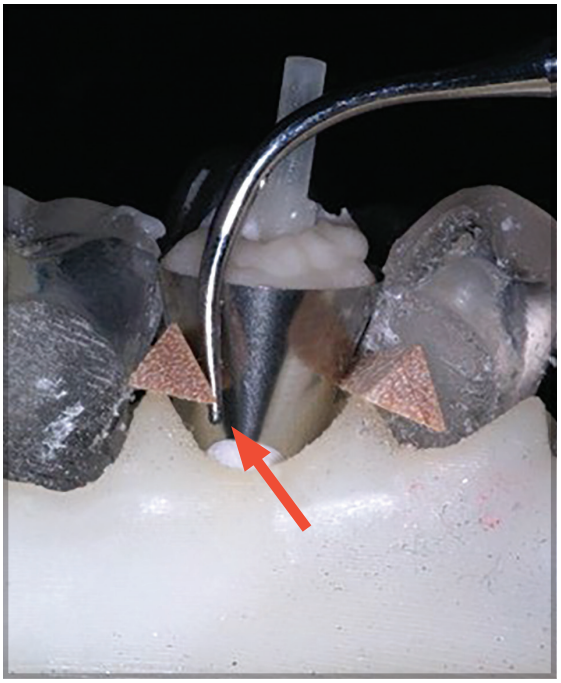


Fig 1. Restorative setup augmented with the ultrasonic tip (arrow) applying 5 seconds of vibration to the outside of the lingual aspect of the matrix band.

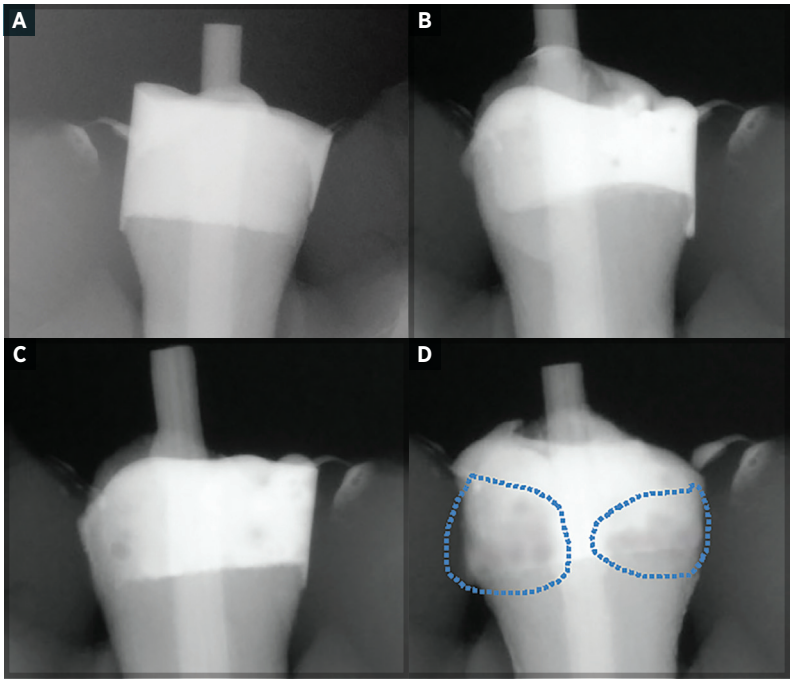


Fig 2. Radiographs representing void severity categories 0 to 3. Blue arrows or dotted lines indicate the presence of voids. A. Category 0. B. Category 1. C. Category 2. D. Category 3.

Core build-up placement

An Original Tofflemire Matrix Band (No. 1, 0.002 inch; Waterpik) was placed and secured with wedges (Sycamore Wood Wedges, size UT; Premier Dental). The core material was placed with the manufacturer-provided syringe, with the endo tip beginning at the most apical aspect of the pulp chamber floor and dispensing up to the occlusal surface in a single layer. For the experimental groups, a Cavitron ultrasonic tip was placed outside of the matrix band, avoiding direct contact with the core material, and activated for 5 seconds (30 kHz, blue zone; Cavitron Jet Plus, Dentsply Sirona) (Fig 1). In the 2 composite resin groups, the LED curing light (430- to 480-nm wavelength, 1470 mW/cm^2) was used to polymerize the core material (Gradia Core) in accordance with the manufacturer's instructions for 20 seconds. Fuji IX is a self-curing glass ionomer material that sets via an acid-base reaction; in the 2 glass ionomer cement groups, the material was allowed to set as described in the manufacturer's instructions.

Standardized radiographic imaging

A standardized radiographic jig was designed and fabricated in acrylic resin (ProJet 7000, 3D Systems). The radiographic images were made with the ProX system (36 × 45-mm rectangular cone diameter, 60 mm; Planmeca USA) with a size 2 sensor (RVG 6100 digital imaging sensor, Carestream Dental) and standardized radiographic settings (60 kV, 7 mA, 0.1 s). Radiographs of all specimens were made in a buccolingual direction, as indexed in the jig.

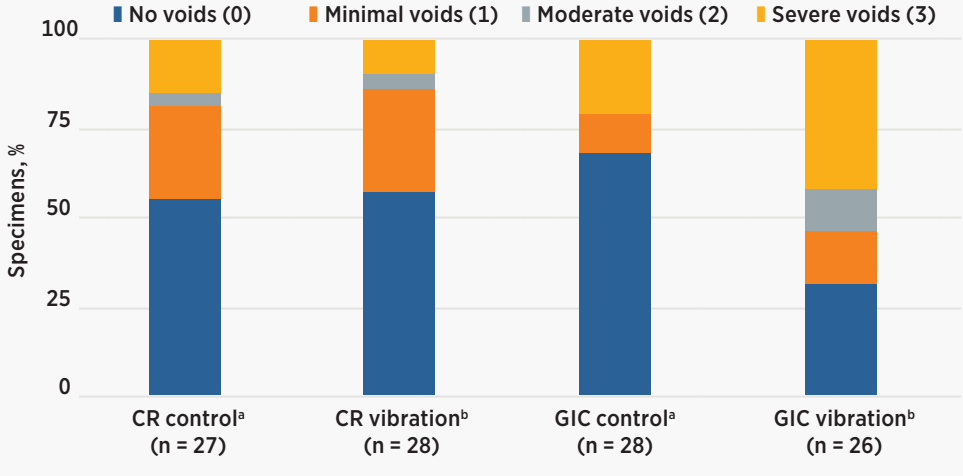
Data collection

The DICOM (Digital Imaging and Communications in Medicine) images were exported from Xray Vision DCV software (Apteryx) and displayed in PowerPoint presentations (Microsoft) for independent review and scoring by 3 calibrated, board-certified clinicians (American Board of General Dentistry). The observers visually identified and quantified the porosity of the core build-up specimens as demonstrated by the presence of bubbles and voids within the material or gaps formed between the core material and the cavity preparation or fiber post in the tooth analog. The severity of bubbles or voids was assessed according to the following criteria:

- Category 0. No voids or bubbles are present.
- Category 1. Voids inside of the core build-up material are visible but minor in number or size. Voids are not at the margins or adjacent to the post.
- Category 2. The number and size of voids are greater than category 1, but clinically acceptable. Voids are not near the margin or adjacent to the post. Replacement before the final restoration is not indicated.
- Category 3. The number and size of voids are clinically significant. Voids are present at a margin and/or adjacent to the post. Radiographic appearance indicates the build-up should be replaced or repaired before the final restoration is placed.

The individual observers were considered calibrated once they achieved 80% agreement with the 4 severity ratings on a separate training subset of 20 radiographs (Fig 2). All 3 observers achieved this calibration criterion in their initial evaluation of the 20 training radiographs. The final scores of the 120 study specimens were determined by agreement of at least 2 raters. If there was no agreement between at least 2 raters for a given radiograph, that radiographic result was considered indeterminant and excluded from analysis.

Chart. Distribution of void severity categories in CR and GIC core build-ups fabricated with or without ultrasonic vibration.



Abbreviations: CR, composite resin; GIC, glass ionomer cement.

[a]Standard placement technique.

[b]Standard placement technique plus 5 seconds of ultrasonic vibration (applied to the outside of the matrix band) immediately after material placement.

Statistical analysis

The sample size of 30 specimens for each of the 4 experimental groups (120 total) was planned a priori to have 80% power (2-sided $\alpha = 0.05$) to detect a reduction in the proportion of voids present from 80% in the control group to 45% in the ultrasonically vibrated group within each of the 2 types of build-up materials. This binary outcome was conservatively planned assuming that categorical ratings of void severity could not be reliably discriminated in the experimental specimens. Because observers met the standardization criterion for the 4-level severity rating, analyses evaluated this more detailed outcome and assessed for linear trends across the ordinal severity scale.

The Fisher exact test was used to compare frequencies of raters' radiographic scores in sonicated vs control specimens within each material type (composite resin vs glass ionomer cement) and in composite resin vs glass ionomer cement specimens within each vibration condition (sonicated vs control). Ordinal logistic regression was used to test the associations of vibration condition and material type and their interactions as independent variables with the 4-level severity rating as the dependent variable. The Cochran-Armitage trend test was used to evaluate for linear trends in severity ratings within the experimental conditions. The Fleiss kappa statistic was calculated to assess agreement across the 3 raters in severity ratings among all analyzed specimens.

Results

The Chart shows the distribution of void severity ratings. In the composite resin groups, the presence and severity of voids were similar with and without vibration. In the glass ionomer groups, the presence and severity of voids increased when vibration was used. Voids were found in 32% of glass ionomer control specimens compared with 69% of the vibration specimens. Clinically unacceptable (category 3) voids were found in 21% of the glass ionomer control specimens compared with 42% of the glass ionomer vibration specimens. The interaction between material and vibration was statistically significant in the ordinal logistic regression model with void severity as the outcome ($P = 0.03$). Within glass ionomer specimens, there was a linear trend for the association of vibration with poorer void severity ratings ($P = 0.01$).

Without ultrasonic vibration (control), 85% of composite resin specimens were clinically acceptable, compared with 79% of glass ionomer specimens. With vibration, 89% of composite resin specimens were clinically acceptable, compared with only 58% of glass ionomer specimens. A linear trend was found for the association of glass ionomer with poorer severity ratings within the vibration condition ($P < 0.01$).

The Fleiss kappa statistic ($\kappa = 0.36$) indicated fair agreement in all severity ratings among the 3 raters. Of the 120 specimens, 11 (9.2%) were omitted because of a lack of consensus among the raters; these omissions were approximately equally distributed among the experimental conditions.

Discussion

Conceptually, applying sonic vibration during placement of a bulk-fill composite resin increases the flowability of the material during placement, resulting in improved marginal and internal adaptation without changing the original composition or physicochemical properties, as has been employed over multiple generations of SonicFill.[14] Additionally, Jarisch et al demonstrated that applying a sonication technique reduces the presence of voids in bulk-fill composite resin materials compared with

traditional incremental placement.[15] The materials evaluated were a packable composite resin and a bulk-fill composite resin material. In contrast, Hirata et al showed that the application of sonication to nanohybrid and bulk-fill composite resin materials produced larger voids, possibly due to the coalescing of smaller voids.[16]

The present study employed a standardized tooth analog preparation design with dual-cured composite resin (Gradia Core) and glass ionomer cement (Fuji IX) core materials to directly compare the effects of ultrasonic vibration on the different materials. Although the tooth analogs were designed to mimic a common clinical scenario, glass ionomer cement may not be the ideal clinical choice for this particular preparation design. However, glass ionomer may be the material of choice for deep margin elevation and other challenging clinical cases. Regardless of the material selected, marginal and internal adaptation and void presence are essential factors to control in the clinical setting. The current study was designed to evaluate the effect of ultrasonic vibration on 2 different materials during placement, although neither material is manufactured or advertised specifically for use with a sonication technique.

While there was no difference in void severity in the composite resin build-ups produced with or without the application of ultrasonic vibration, the glass ionomer cement build-ups fabricated with vibration showed more significant void formation than did glass ionomer cement build-ups fabricated without vibration. Therefore, the null hypothesis was partially rejected. These results suggest that differences in the physicochemical properties of composite resin and glass ionomer cement may result in different behaviors of these materials under ultrasonic vibration. Unlike light-cured resin materials, once glass ionomer material components are combined and activated, they set by an acid-base reaction within 2 to 6 minutes, and full maturation occurs over several days or even several months.[19] Further investigation is needed to study the effect of ultrasonic vibration early in the acid-base reaction setting process of glass ionomer cement materials.

In the present study, vibration was introduced by utilizing an ultrasonic scaler tip. Previous studies employing a sonication technique used a handpiece specifically designed for use with the restorative materials during placement. In the investigation by Hirata et al, composite resin materials were injected into a compule that was compatible with the SonicFill handpiece.[16] Using this technique, sonication can be applied directly to the material during placement. In the present experimental design, the ultrasonic tip used to vibrate the materials was applied to the external surface of the matrix band after the restorative materials were placed. A Cavitron instrument was utilized because it is already accessible in many dental offices, avoiding the need to purchase additional instrumentation such as an ultrasonic handpiece, and because it could be employed with many different restorative materials. However, the ultrasonic instrument used is not specifically designed for this type of application. It is possible that if the armamentarium and material formulations could be optimized, glass ionomer cement and other bulk-fill composite resin materials could, like SonicFill, benefit from ultrasonic vibration during placement to reduce voids and improve adaptation. However, in the present study, this modified technique with a readily available armamentarium and selection of materials did not demonstrate feasibility as an adjunctive procedure.

In addition to a standard preparation design, 3D-printed acrylic resin tooth analogs fabricated from ZP151 calcium sulfate hemihydrate were utilized in place of extracted teeth to optimize uniformity among specimens. The radiographic appearance of calcium sulfate hemihydrate is remarkably like dentin, making it an ideal choice for this and similar study designs.

Conclusion

Within the limitations of this in vitro study design and evaluation based on radiographic appearance, the application of ultrasonic vibration to a glass ionomer cement appears to introduce more voids and result in a less acceptable build-up restoration. Vibration was not found to have an effect on the severity of voids in a dual-cured composite resin. These results suggest that the application of ultrasonic vibration during placement of core build-up materials may not be clinically advantageous for improving restorative outcomes.

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Conflicts of interest

None reported.

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