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EFFECT OF ULTRASONIC VIBRATION ON THE PRESENCE OF VOIDS IN CORE BUILDUP MATERIALS

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MASTER'S THESIS

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ABSTRACT

EFFECT OF ULTRASONIC VIBRATION ON THE PRESENCE OF VOIDS IN CORE BUILDUP MATERIALS

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Introduction: The core buildup procedure is often utilized to restore teeth with limited remaining coronal tooth structure. Voids have been observed radiographically within glass-ionomer and resin-based core materials, potentially compromising the mechanical strength of the fully restored tooth. The presence of large or numerous voids may require buildup replacement before a final restoration can be delivered.

Objective: The purpose of this *in vitro* study was to determine whether applying an ultrasonic vibration technique during core buildup placement will reduce the presence of radiographically detectable voids.

Methods: One hundred twenty 3D-printed acrylic resin mandibular premolar analogs were fabricated and randomly assigned to four groups (n=30/group). Glass ionomer or dual-cure resin materials were placed with or without vibration during placement. Final core buildups were assessed radiographically using XrayVision DCV software and rated by three independent and calibrated clinicians based on a four-category scale for presence and size of voids. Ordinal logistic regression and Chi-square tests for trend were used to compare radiographic void scoring in vibrated versus control samples within each material type. Fleiss' kappa was used to evaluate inter-rater agreement.

Results: In an ordinal logistic regression model of void severity rating as the outcome, a significant interaction was found between glass ionomer or resin and the use of ultrasonic vibration ($p = 0.03$). Vibration was associated with worse void severity ratings in glass ionomer ($p < 0.01$). Fleiss' kappa was 0.36 (fair agreement) when comparing all severity ratings between the three raters.

Conclusion: Applying ultrasonic vibration resulted in worse ratings for radiographic presence of voids in glass ionomer compared to control. No effect of vibration was found in the resin group. These results suggest that the application of ultrasonic vibration during core buildup placement may not be clinically advantageous in improving restorative outcome.

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cm	centimeters
in	inches
kHz	kilohertz
kV	kilovolts
mA	milliamps
mm	millimeters
MOD	mesio-occlusal-distal
mW	milliwatts
nm	nanometers
®	registered trademark
s	seconds

CHAPTER I: REVIEW OF THE LITERATURE

Major changes after teeth have been treated with endodontic therapy include loss of tooth structure, and possible discoloration. Caries, facture, or endodontic access preparation, all contribute to the loss of tooth structure and subsequent changes in tooth biomechanics. The literature reports 20% to 63% [1] and 14% to 44% [1,2] reduction in tooth integrity following occlusal access and mesio-occlusal-distal (MOD) preparations, respectively.

Endodontically treated teeth have a higher risk of crown fracture due to tooth structure loss, with weaken mechanical properties leading to the fracture of roots over time. To maximize the longevity of endodontically treated teeth, restorations should be designed to 1. prevent fracture of the remaining tooth structure, 2. Inhibit the reinfection of the treated canals, and 3. restore the lost tooth structure. [3]

Depending on the amount of remaining tooth structure, endodontically treated teeth can be restored with different materials utilizing either direct or indirect techniques. In most cases, when a significant amount of coronal tooth structure has been compromised due to caries, restorative procedures and endodontic treatment, a full cuspal coverage crown is indicated. To retain a crown, remaining coronal structure must be prepared accordingly. In majority of cases, the insertion of a post into 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 effect the prevalence of root fracture on endodontically treated teeth, as well as the failure mode of the post and core. Coelho et al. concluded that more homogenous stress distribution was observed when glass and carbon fiber posts were utilized, resulting in lower incidents of root fracture in endodontically treated teeth. This has been attributed to the physical properties of glass and carbon fiber posts being similar to dentin, including their modulus of elasticity (Young's 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 post and cores is debonding from the tooth, resulting microleakage, secondary caries, to mobility and dislodge of final restoration. In contrast, teeth restored with cast metal post and cores usually have catastrophic failure, such as vertical root fracture, leading to a localized periodontal defect and ultimately requiring extraction of the tooth. [8,9]

The core buildup replaces the missing coronal tooth structure, providing the proper retention and resistance form for the final restoration. [3,5] The materials selected for core buildup can include metal (amalgam or cast gold), resin composite, glass ionomers and resin reinforced glass ionomers. Favorable physical characteristics of core material include 1. high compressive strength and flexural toughness, 2. dimensional stability in wet environment, 3. ease of manipulation, 4. rapid setting time, 5. the ability to bond to both tooth structure and post, and 6. biocompatibility and cariostatic properties. Popular core materials in clinical use include amalgam, composite resin, cast metal or ceramic, and sometimes glass ionomer materials. [3,5]

In recent years, composite resin-based core materials have gained popularity. The ability to bond to both tooth structure and many post materials, ease of manipulation, fast setting, and radiographically translucent or highly opaque formulations are some of the advantages of utilizing composite core resins as a core buildup material. [3] The literature has shown that composite cores have similar or better strength to amalgam cores to support all ceramic crowns. [10-12] The degree of complete curing of the resin heavily influences the bond strength of composite resin core materials 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 photo-initiated curing alone may be challenging. This is especially true in deeper core buildup preparations with undercuts. [3]

Glass ionomers and modified glass ionomer cements can be used to restore small buildups or to fill undercuts in prepared tooth. [3,5] Their ability to chemically bond to tooth structure, purported fluoride releasing ability, natural tooth colored and biocompatibility are few of main advantages to using glass ionomers. [5] However, they may be contraindicated in anterior teeth due to low strength and fracture toughness. [3] In the situation of 1. Substantial remaining dentin exist, 2. Extent of core buildup is minimal to moderate (not replacing functional cups), and 3. Caries control is indicated, glass ionomer could be used as a core buildup material. [3]

Soares, et al., showed that bulk-fill resin composites are able to adapt to the cavity walls better than conventional incrementally filled composites. [13] Kerr developed a special sonic handpiece to be utilized with their bulk fill resin composite (SonicFill^{TM}, Kerr, Brea, CA). Sonication technology has been well studied in bulk fill resin composite materials and shown to decrease viscosity during delivery and possibly to enhance adaption to the cavity preparation. [14]. One study has shown 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 resin composite placement, depending on the restorative material used. [16] Voids have been observed in bulk fill resin composites and large composites filled incrementally. It has become a growing concern to many clinicians. An increased number and size of voids could result in increased water absorption, possible fracture and crack propagation, leading to staining, compromised mechanical strength and decreased wear resistance. [15-17] Porosity appearing in the resin composite and glass ionomer-based materials may be the result of 1. manufacturing and packaging [16], 2. Spaces formed between increments during placement, and 3. Tacky handling properties prior to the complete setting of the materials [18]

No prior studies, according to the authors' knowledge, have applied a sonication technique to dual cured core buildup materials and glass ionomer-based core materials. Therefore, the purpose of this *in vitro* study was to evaluate the effect of sonic vibration during material placement on the presence of voids in core buildup materials, as evaluated using plain film radiographs. The null hypothesis was that there would be no difference in the radiographic assessment of voids present in resin- or glass ionomer-based core buildup materials placed with or without sonic vibration.

CHAPTER II: MATERIALS AND METHODS

This was an *in vitro* study investigating the outcomes of different dental restorative material placement techniques on final radiographic appearance. Three independent, calibrated, board-certified clinicians reviewed the radiographs and scored each sample specimen based on relative number/size of voids present. Categorical data was analyzed to determine if there was a statistically significant difference in radiographic scores based on clinical technique used (with or without sonic vibration during material placement).

A 3D printed acrylic resin mandibular right quadrant model with a removable second premolar was designed and fabricated using a 3D printer and ZP151 calcium sulfate hemihydrate (3D systems, Inc., Japan). To simulate a clinical premolar buildup preparation following endodontic therapy and loss of tooth structure due to fracture, the removable premolar analog was designed with a missing lingual cusp (**Figure 1**). A drill stent (**Figure 2**) was fabricated with acrylic material (3D printer, 3D system Inc., Japan) for preparing an endodontic access, pulp chamber, and canal post space prepared to a size 7 (most apical diameter =1.75 mm). One hundred twenty duplicates of the removable premolar analog were fabricated to fit the mandibular quadrant model.

Figure 1: design of 3D printed tooth analog

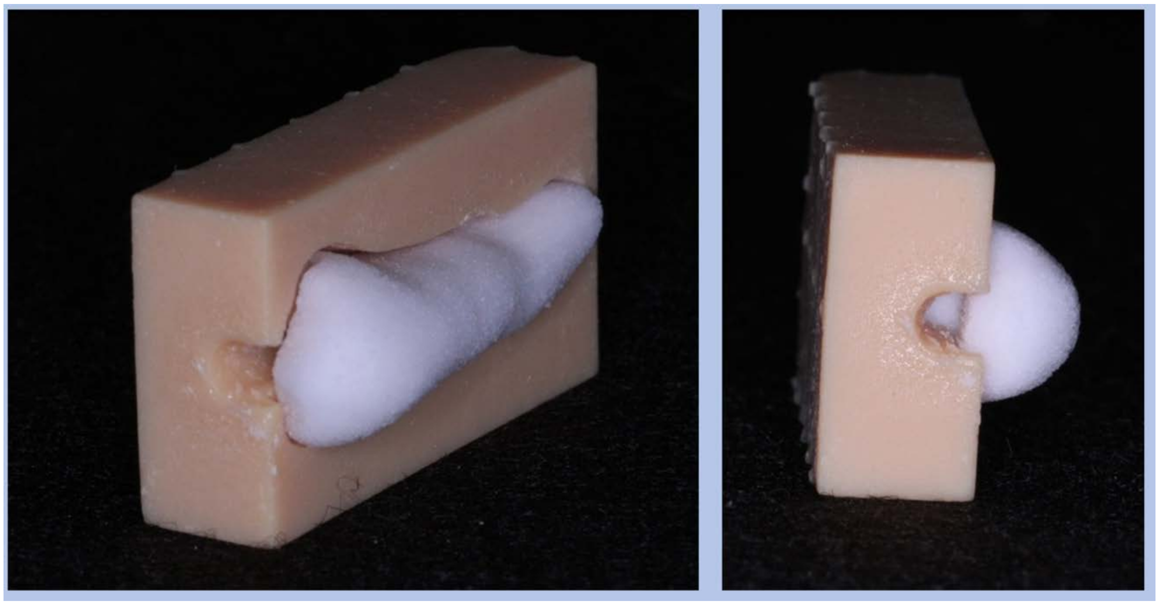

Figure 2: Design of drill stent for preparation of endodontic access, pulp chamber, and post space.

Study design

One hundred twenty premolar analogs were randomly divided by core material and placement technique into 4 groups of 30 (**Figure 3**):

1. Dual cured resin composite (Gradia® Core, GC America; Alsip, IL, USA) placed with a fiber post. Core material was placed with a bulk insertion technique per manufacturer's instructions (Control).
2. Dual cured resin composite placed with a fiber post and a bulk insertion technique following manufacturer's instructions, with the additional step of five seconds of ultrasonic vibration following material placement and before light curing.

3. Glass ionomer (Fuji IX®, GC America; Alsip, IL, USA) applied with the use of a fiber post. Glass ionomer was placed with a bulk insertion technique per manufacturer's instructions (Control).
4. Glass ionomer placed with a fiber post and a bulk insertion technique following manufacturer's instructions, with the additional step of five seconds of ultrasonic vibration following material placement.

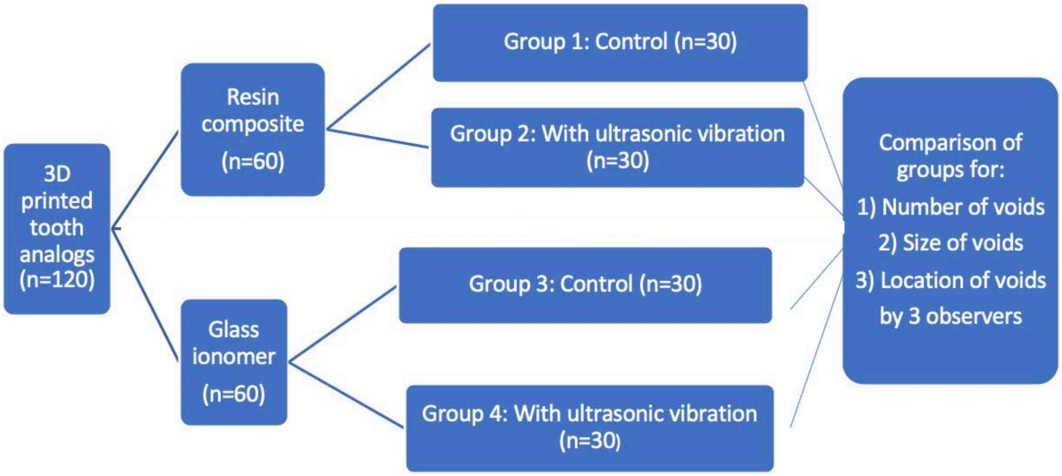

Figure 3: Flowchart of study design. Half of the 120 prepared tooth analogs received a dual-cured resin composite buildup, with the other half receiving a glass ionomer buildup. Groups were further subdivided to either be restored using a bulk-fill technique alone, or bulk-filled with the addition of 5 seconds of ultrasonic vibration. Radiographs were made of each tooth, and 3 calibrated, independent observers scored each radiograph for voids based on standardized criteria.

Glass fiber post cementation

ParaPostXP fiber posts (Coltene/Whaledent Inc., Cuyahoga Falls, OH, USA) were utilized in all tooth analogs. Core materials Gradia® Core and Fuji IX® were placed into the canal space with their respective manufacturer-supplied dispensing tips. A ParaPost

XP size 7 fiber post was inserted into the canal space of each analog, then cured for 20 seconds with an LED curing light (3M ESPE Elipar S10, 1200 mW/cm^2, 430-480 nm wavelength, St. Paul, MN, USA).

Core buildup placement

A Waterpik original Tofflemire matrix band (No.1, 0.002in, Henry Schein, Melville, NY) was placed and secured with wedges (Sycamore wood wedges, size UT, Patterson Dental, Saint Paul, MN). Core material was placed with the manufacturers' provided syringe with endo tip beginning at the most apical aspect of the pulp chamber floor and dispensing up to the occlusal surface in a single increment. For groups employing the augmented ultrasonic vibration technique (Group 2 and 4), the Cavitron tip (Dentsply, York, PA USA) was placed outside of the matrix band, avoiding direct contact with the core material, for 5 seconds (30 kHz, blue zone, Cavitron Jet plus, Dentsply, York, PA, USA). (**Figure 4**) The core material (Gradia® Core) was then light cured per manufacturer's instructions with an Elipar^{TM} S10 LED curing light (430-480nm, 1470 mW/cm^2,) for 20s. Fuji IX® is a self-cured glass ionomer material that sets via an acid-base reaction. The material was allowed to set per manufacturer's instructions for use.

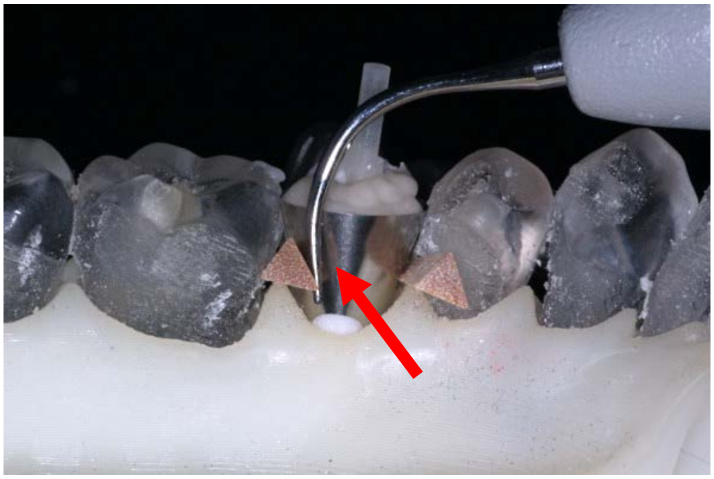

Figure 4: Restorative set up augmented with Cavitron tip. Red Arrow: Cavitron tip placed on the outside of the lingual aspect of the matrix band

Standardized radiographic imaging

A standardized radiographic jig was designed and fabricated with acrylic material (3D printer, 3D system Inc., Japan). The radiographic images were made with a Planmeca ProX system (36x45mm rectangular cone diameter, 60mm, Planmeca USA, Inc., Hoffman Estates, IL, USA) with size 2 sensor (Carestream RVG 6100, Carestream, Rochester, NY, USA) and standardized radiographic settings (60kV, 7mA, d.100s). Radiographs of all samples were made in a buccolingual direction, as indexed in the jig (**Figure 5**).

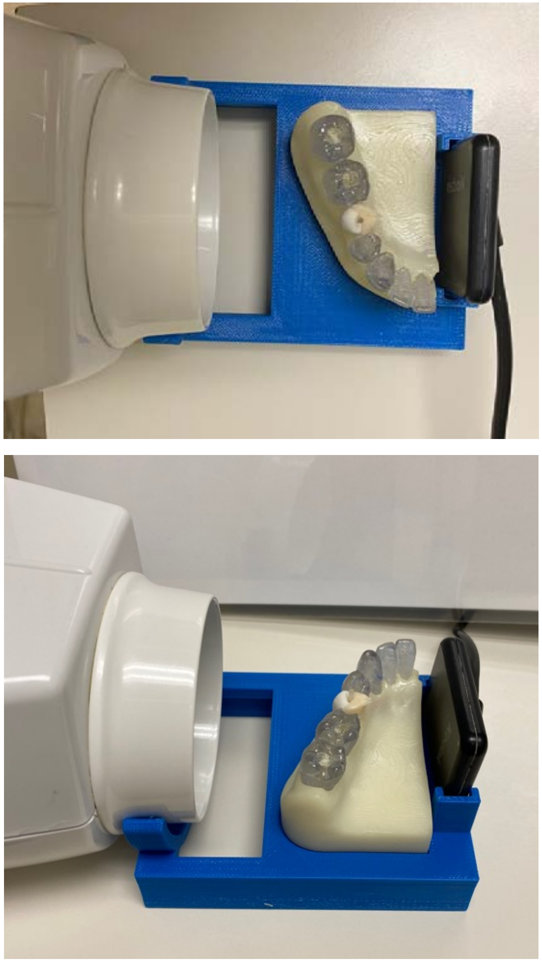

Figure 5: Tooth analog in mandibular left quadrant model placed in jig for standardized radiographic exposure.

Data collection

The DICOM images were exported from XrayVisionDCV software (Apteryx, Inc., Akron, OH, USA) and displayed in Microsoft PowerPoint for independent review by three calibrated observers to visually identify and quantify core buildup porosity as expressed by the presence of bubbles or voids both within the material and gaps formed between the core material and cavity preparation in the tooth analog. Observers were trained by an expert reviewer who demonstrated scoring in a subset of example radiographs used for training only. Standardized scores were based on a 4-level severity scale (**Figures 6 and 7**).

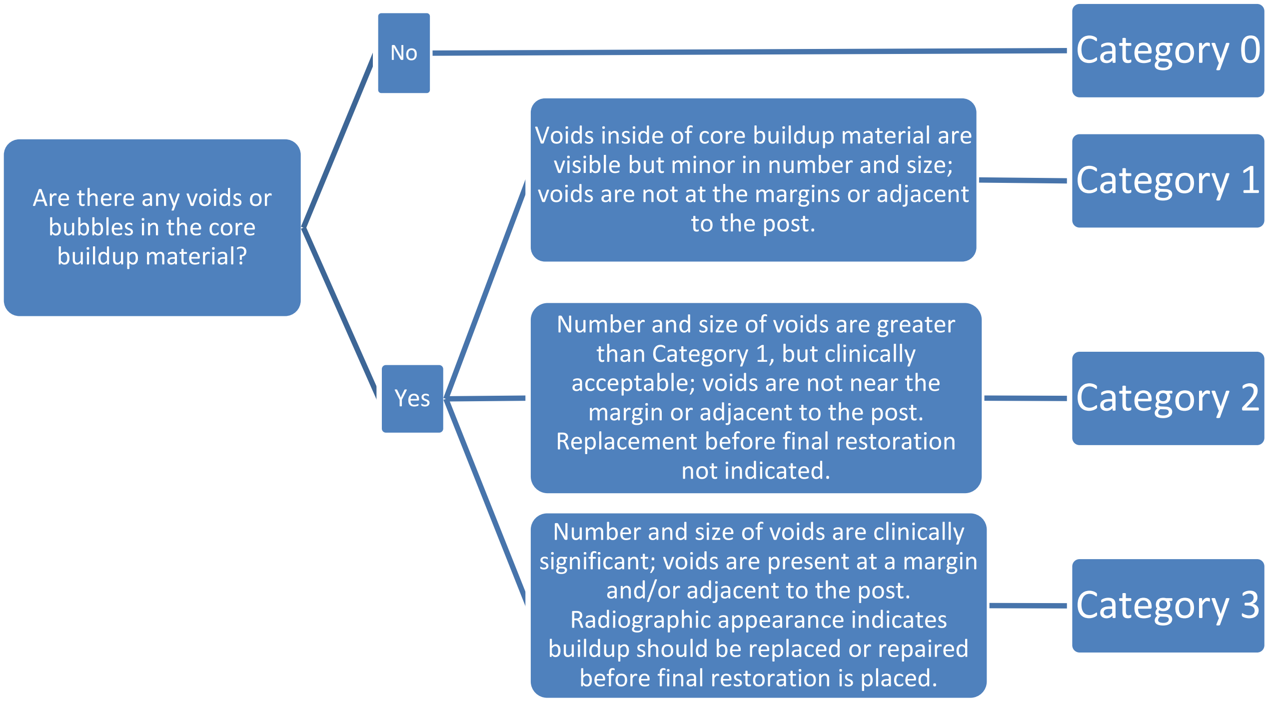

Figure 6: Evaluation standard and criteria

Individual observers were considered calibrated once they achieved 80% agreement with the 4-level ratings provided by the expert reviewer, using a separate training subset of 20 radiographs. All three observers achieved this calibration criterion in their initial evaluation of the 20 training radiographs. Final scores of the 120 study samples were determined by agreement of at least two raters. If at least two raters did not give the same score for a given radiograph, that radiograph result was considered indeterminate and excluded from analysis.

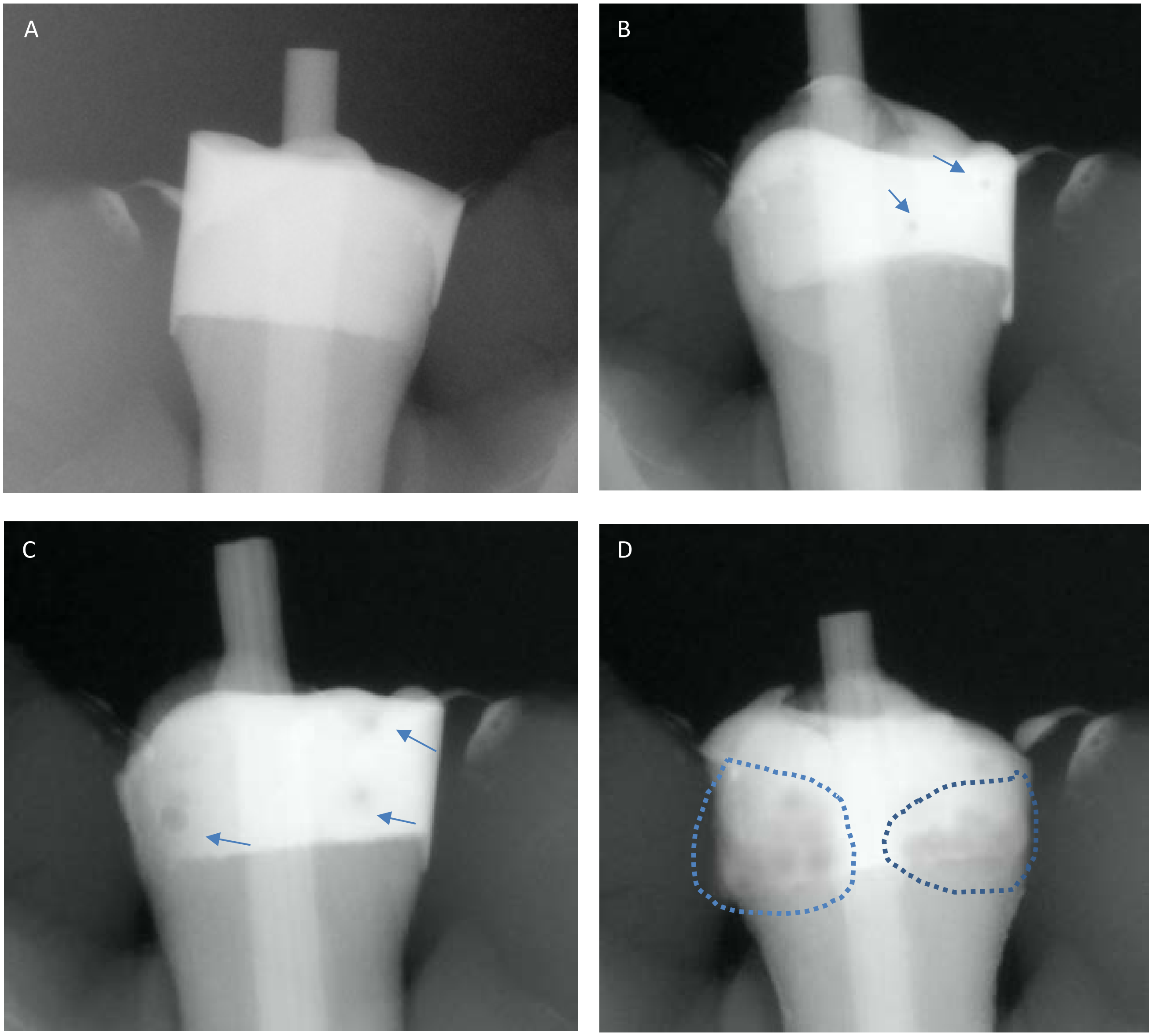

Figure 7: Representative radiographs for Category 0-3. A: Category 0, B: Category 1, C: Category 2, D: Category 3. Blue arrows or dotted lines indicated presence of voids.

Statistical analysis

The study sample size of 30 samples per each of the four experimental groups (120 total samples) was planned a priori to have 80% power (two-sided alpha of 0.05) to detect a reduction in the proportion of any voids present from 80% in the control group to 45% in the ultrasonically vibrated group, within each of the two types of buildup materials. This binary outcome was conservatively planned assuming categorical ratings of void severity could not be reliably discriminated in our experimental samples. Because observers met standardization criteria for the 4-level severity rating, analyses evaluated this more detailed outcome and assessed for linear trends across the ordinal severity scale. Fisher's exact tests were used to compare frequencies of raters' radiographic scores in 1) sonicated versus control samples within each material type (glass ionomer and resin), and 2) in glass ionomer versus resin samples within each vibration condition (sonicated versus control). Ordinal logistic regression was used to test the associations of vibration condition, material type, and their interaction as independent variables and 4-level severity rating as the dependent variable. Cochrane-Armitage tests for trend were used to evaluate for linear trends in severity ratings within experimental conditions. Fleiss' Kappa was calculated to assess agreement across the three raters in severity ratings among all analyzed samples.

CHAPTER III: RESULTS

Figure 8 shows the distribution of severity ratings by placement technique for each material. In the glass ionomer group, the presence and severity of voids increased when vibration was used. Voids were found in 32% of control glass ionomer samples compared with 69% in the vibration condition. 21% of the control samples had clinically unacceptable voids (Category 3), versus 42% in the vibration condition. In the resin group, the presence and severity of voids was similar with and without vibration. The interaction between material and vibration use was statistically significant in the ordinal logistic regression model of void severity as the outcome (p = 0.03). Within glass ionomer samples, there was a linear trend in the association of vibration with poorer void severity ratings (p = 0.01).

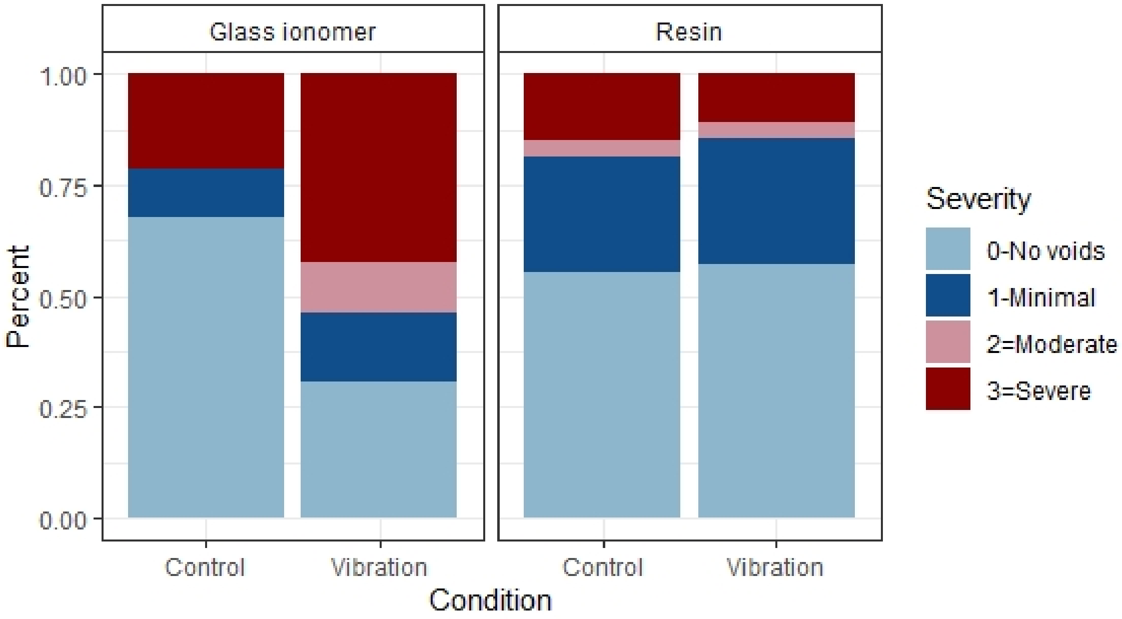

Figure 8: Distribution of severity ratings by condition for each material

Figure 9 shows the results comparing severity by material, within each condition.

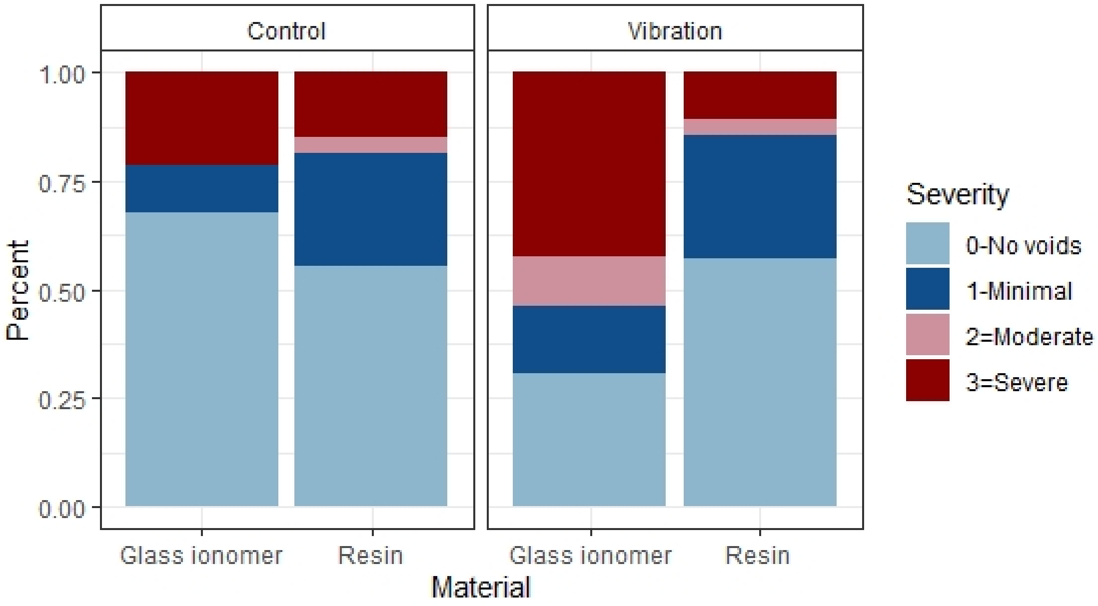

Figure 9: Results from Figure 8 displayed to compare severity by material, within each condition

Without sonication, 79% of glass ionomer samples were clinically acceptable, compared with 89% in resin. With sonication, only 58% glass ionomer samples were clinically acceptable, versus 85% in resin. A linear trend was found in the association of glass ionomer with poorer severity ratings, within the vibration condition ($p < 0.01$).

Fleiss' kappa was 0.36 (fair agreement) when comparing all severity ratings between the three raters. 11/120 (9.2%) samples were omitted due to no consensus among raters and were approximately equally distributed among experimental conditions.

CHAPTER IV: DISCUSSION

Conceptually, applying sonic-activation during the placement of a bulk-fill composite material increases the flowability of the material during placement, resulting in improved marginal and internal adaptation, without changing its original composition and physicochemical properties, and has been employed over multiple generations of SonicFill™ (Kerr). [14] Additionally, Jarisch et al. (2016) demonstrated that applying a sonication technique reduces the presence of voids in sonic-activated bulk-fill resin materials compared to traditional incremental placement. The materials evaluated were a packable composite and a bulk-fill resin material. In contrast, Hirata et al. (2018) showed that the application of sonication to nanohybrid composite and bulk fill composite materials produced larger voids, possibly due to the coalescing of smaller voids.

Our study employed a standardized preparation design with a glass ionomer (Fuji IX®) and a dual cured resin-based core material (Gradia® Core) to directly compare the effects of sonic vibration on these two different materials. Though the tooth analogs were designed to mimic a common clinical scenario, glass ionomer may not be the clinically ideal choice with 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 specific material selected, marginal and internal adaptation, as well as void presence, are essential factors to control for in the clinical setting. Current study was designed to evaluate the effect of sonication on two different materials during placement, though neither material is manufactured or advertised to be used specifically with a sonication technique.

It was found that while there was no difference in void severity in the resin-based composite groups with or without the application of sonic vibration, the glass ionomer with vibration group showed *more* significant void formation than without. These results suggest that differences in the physicochemical properties of resin-based composite and glass ionomer may result in different behavior of these materials under sonic vibration. Unlike light cured resin materials, once glass ionomer material components are combined and activated, they set by an acid-base reaction within 2-6 minutes, with full maturation occurring over several days or even several months. [19] Further investigation is needed to study the effect of sonic vibration early in the acid-base reaction setting process with glass ionomer.

In the present study, sonication was introduced by utilizing a ultrasonic scaler tip. Previous studies employing a sonication technique utilized a specific handpiece designed to be used with the materials during placement. In the investigation by Hirata, et al. (2018) resin composite materials were injected into a compule that was compatible with a SonicFill™ handpiece. Using this technique, sonication can be applied directly to the material during placement. In our 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 in our study design due to its accessibility in many dental offices, and could possibly forgo the need to purchase additional instrumentation, such as an ultrasonic handpiece, and could be employed with many different restorative materials. However, the ultrasonic instrumentation used here is not specifically designed for this type of application. It is possible that, like SonicFill™, if armamentarium and material formulation can be optimized, even glass ionomer and other bulk-fill resin materials could benefit from sonic vibration during placement to reduce voids and improve adaptation. However, in our study, employing this modified technique with readily available materials and armamentarium did not demonstrate feasibility as an adjunctive procedure.

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

CHAPTER V: CONCLUSION

In conclusion, within the limitations of this *in vitro* study design, applying ultrasonic vibration to a glass ionomer material appears to introduce more voids and result in a less acceptable buildup restoration based on radiographic appearance. No effect of vibration was found in the resin group. These results suggest that the application of ultrasonic vibration during core buildup placement may not be clinically advantageous in improving restorative outcomes.

REFERENCES

1. Reeh ES, Messer HH, Douglas WH. Reduction in tooth stiffness as a result of endodontic and restorative procedures. *J Endod*. 1989;15(11):512-516. doi:10.1016/S0099-2399(89)80191-8
2. Morin D, Douglas WH, Cross M, DeLong R. Biophysical stress analysis of restored teeth; experimental strain measurement. Dent Mater 1988;4:41-8.
3. Hargreaves K, Berman LH. Cohen's pathway to pulp. 2016. 11th ed. Chap 22, 818-848.
4. Schwartz RS, Robbins JW. Post placement and restoration of endodontically treated teeth: a literature review. *J Endod*. 2004;30(5):289-301. doi:10.1097/00004770-200405000-00001
5. Robbins, J.W., *Restoration of endodontically treated teeth, in Fundamentals of Operative Dentistry. A contemporary approach*, J.B. Summitt, et al., Editors. 2006, Quint Pub Co Inc. p. 570-590.
6. Coelho CS, Biffi JC, Silva GR, Abrahão A, Campos RE, Soares CJ. Finite element analysis of weakened roots restored with composite resin and posts. *Dent Mater J*. 2009;28(6):671-678. doi:10.4012/dmj.28.671
7. Peroz I, Blankenstein F, Lange KP, Naumann M. Restoring endodontically treated teeth with posts and cores—a review. Quintessence Int. 2005 Oct;36(9):737-46.
8. Ferrari M, Cagidiaco MC, Goracci C, et al. Long-term retrospective study of the clinical performance of fiber posts. *Am J Dent*. 2007;20(5):287-291.
9. Schmitter M, Hamadi K, Rammelsberg P. Survival of two post systems--five-year results of a randomized clinical trial. *Quintessence Int*. 2011;42(10):843-850.

10. Yüzügüllü B, Çiftçi Y, Saygılı G, Canay Ş. Diametral tensile and compressive strengths of several types of core materials. *J Prosthodont*. 2008;17(2):102-107. doi:10.1111/j.1532-849X.2007.00269.x
11. Agrawal A, Mala K. An in vitro comparative evaluation of physical properties of four different types of core materials. *J Conserv Dent*. 2014;17(3):230-233. doi:10.4103/0972-0707.131782
12. Saygili G, Mahmali SM. Comparative study of the physical properties of core materials. Int J Periodontics Restorative Dent. 2002 Aug;22(4):355-63.
13. Soares CJ, Rosatto C, Carvalho VF, Bicalho AA, Henrigues J, Faria-E-Silva AL. Radiopacity and porosity of bulk-fill and conventional composite posterior restorations-digital X-ray analysis. Oper Dent.2017 Nov/Dec;42(6):616-625.
14. Kerr Corporation. SonicFill 3 [website]. 2018. https://www.kerrdental.com/kerr-restoratives/sonicfill-3-single-fill-composite-system#docs. Accessed June1,2020.
15. Jarisch J, Guevara PH, Greenwood WJ, Dunn WJ. Microcomputed tomographic comparison of posterior composite resin restorative techniques: sonicated bulk fill versus incremental fill. Gen Dent. 2016 Sep-Oct:64(5):20-3.
16. Hirata R, Pacheco RR, Caceres E, Janal MN, Romero MF, Giannini M, Coelho PG, Rueggeberg FA. Effect of Sonic resin Composite Delivery on Void Formation Assessed by Micro-computed Tomography. Oper Dent. 20018 Mar/Apt;43(2): 144-150.
17. Mentink AG, Meeuwissen R, Hoppenbrouwers PP, Käyser AF, Mulder J. Porosity in resin composite core restorations: the effect of manipulative techniques. *Quintessence Int*. 1995;26(11):811-815.

18. Heymann H, Swift J, Ritter A, Sturdevant CM. Sturdevant's Art & Science of Operative Dentistry, 6th edition. 2013. Chap 8,216-228.
19. Nicholson JW. Maturation processes in glass-ionomer dental cements. *Acta Biomater Odontol Scand*. 2018;4(1):63-71. Published 2018 Jul 31. doi:10.1080/23337931.2018.1497492