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FRACTURE STRENGTH OF CAD/CAM VERSUS CONTEMPORARY BIS-ACRYL PROVISIONAL CROWNS

A manuscript

Presented to the Faculty of the Advanced Education in General Dentistry, Two-Year Program,

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And the Uniformed Services University of the Health Sciences – Post Graduate Dental College

In Partial Fulfillment of the Requirements for the Degree of

Master of Science in Oral Biology

By

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Abstract

COMPARING FRACTURE STRENGTHS OF DENTAL PROVISIONAL CROWN MATERIALS BY METHOD OF FABRICATION: CONTEMPORARY BIS-ACRYL, CAD-MILLED AND CAD PRINTED

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Introduction: Provisional restorations play an important role in modern dental treatments. These restorations protect teeth and maintain space until delivery of definitive restorations. Milled and traditional chair-side provisional fabrication techniques are widely used in clinical practice. The use of CAD/CAM printing for fabrication of provisional crowns is still a relatively new concept, and more studies comparing this material to more traditional methods for temporary fabrication are needed. Evaluation of fracture strength is just one way to compare and contrast provisional materials.

Objective: To compare the fracture strength and mode of fracture of directly fabricated contemporary bis-acryl provisional crowns compared to CAD/CAM milled and printed provisional crowns in a laboratory environment.

Methods: Bis-acryl based materials, Luxatemp Ultra (LT, DMG) was used to fabricate conventional provisional crowns. The CAD/CAM provisional crowns polymethyl methacrylate Telio CAD (TC, Ivoclar Vivadent) were milled from monolithic discs and Temporary CB Resin (CB, Formlabs) were printed on a Form 3 SLA Printer. Crowns were cemented with temporary cement (TempBond NE, Kerr) onto 3D-printed photopolymer resin model dies (Formlabs, n=25/group). A universal testing machine (MTS 858 Mini Bionix II test system) applied a compression load at a crosshead speed of 1 mm/min to individual samples until failure. Force values at failure and modes of fracture were recorded.

Results: The force to failure in newtons for each group (Mean $\pm$ SD) were 2702 $\pm$ 354 for TC, 2254 $\pm$ 347 for LT, and 2334 $\pm$ 456 for CB. Fracture strength of TC was significantly greater than those of LT and CB $p<0.01$. Higher force required to create complete fracture (fracture pattern 4) than the other modes of fracture $p<0.01$, and TC was more likely to fail in this manner at a rate of 60% compared to 36% and 32% for Materials CB and LT respectively.

Conclusion: Fracture strength was significantly higher for TC compared to the other materials tested, and there was no significant difference in fracture strengths between CB and LT. The printed material, CB, appears to perform similarly to chair-side bis-acryl resin material where fracture strength was concerned.

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LIST OF ABBREVIATIONS

LT ----------------LuxaTemp Ultra
PMMA----------- Polymethyl methacrylate
TC ----------------Telio CAD
CB ---------------Temporary CB Resin
CAD/CAM -----Computer Aided Design/Computer Aided Manufacturing

BACKGROUND

Provisional restorative materials play an integral role in prosthetic dentistry and the fabrication of interim prostheses. An interim prosthesis is necessary to enhance esthetics, stabilization and or function for a limited period of time, after which it is to be replaced by a definitive dental or maxillofacial prosthesis[1, 2]. A good provisional restoration should effectively replicate the natural tooth form and seal the prepared tooth surface from the external environment. By replication of the natural tooth form, the provisional restoration can provide positional stability within the dental arch and make the tooth easily cleansable, which protects the periodontium. Sealing the prepared tooth surface protects the remaining tooth structure and the pulp of the tooth from bacterial biofilm and thermal irritants. The provisional should also be capable of withstanding masticatory forces without breakage or dislodgement, and be esthetic, particularly when being used to restore an anterior tooth[3]. In the modern dental practice provisional restorations may be fabricated via direct or indirect methods[2, 4].

Direct fabrication of a provisional restoration is accomplished with use of a negative matrix of the proposed restoration, which can be filled with a resin material that can either be hand mixed or dispensed from an auto-cartridge[3]. This uncured, flowable resin filled matrix is then placed over the prepared tooth surface and may be light-cured, self-cured, or dual-cured depending on the material used[3]. The cured restoration is then removed, trimmed, and polished to improve the contour of the restoration and remove any overhangs or defects. Materials traditionally used to fabricate direct provisional restorations include the traditional self-cure poly methyl methacrylate and bis-acryl base resins which may or may not contain inorganic fillers to improve strength characteristics[2]. The most significant advantage to directly fabricated provisionals is expedience, because of the added laboratory time to pour casts, scan, design, and manufacture a CAD/CAM provisional restoration.

Prior to the introduction of CAD/CAM indirect provisionals the method for making indirect provisional restorations was much like direct fabrication, but by forming the provisional on a cast of the prepared tooth rather than intraorally. These traditional indirect provisional restorations demonstrated better fit and better margins than those fabricated directly. This is primarily because directly fabricated provisional restorations must be removed from the tooth before complete polymerization of the material to avoid locking into undercuts. The disadvantage to removing the provisional prior to complete polymerization is due to deformation due to the manipulation of the restoration during removal and the absence of the supporting form provided by the prepared tooth[3]. Provisional restorations can also be indirectly made using CAD/CAM and have demonstrated comparable to, if not superior, fit and strength characteristics compared to traditional direct or indirect methods[5, 6].

Fabrication of 3D printed provisional restorations is a relatively novel concept in the realm of CAD/CAM dentistry, and fracture strength studies on these types of restorations are still limited. One study from Tahayeri et al. found that 3D printed provisionals perform comparable to bis-acryl and better than direct PMMA provisionals[7]. Another study reported that flexural strength of 3D printed visible-light-cured microhybrid filled composite resin was lower than those of milled CAD/CAM and conventional heat-cured PMMA resins[8]. It was reported that there was no statistically significant difference in fracture strengths between 3D printed, milled resin, and direct fabricated bis-acryl provisional crowns[6]. The purpose of this study was to compare the fracture strengths and assess the mode of fracture for molar crown provisionals fabricated using traditional bis-acryl, milled PMMA and 3D printed materials.

Null Hypothesis:
There is no statistically significant difference in fracture strength between CAD/CAM-fabricated provisional crowns fabricated by subtractive manufacturing methods (milling), provisional crowns fabricated by additive manufacturing methods (3D printing), and crowns directly fabricated with bis-acryl material in a laboratory setting.

Study Procedures

Study overview:
The experimental design will be based on studies: Abdullah et al. (2016 and 2018), Karaokatan et al. (2014), and Manoharan et al. (2018) [4,9,10]. This study will evaluate and compare the fracture strengths of CAD/CAM materials and one chairside provisional material. The chairside material to be tested: Luxatemp Ultra (Bis-acryl; DMG America, Ridgefield Park, NJ, USA). The two CAD/CAM materials to be tested are: milled Telio CAD (PMMA; Ivoclar Vivadent, Schaan Leichtenstien) and 3D printed Temporary CB Resin (Formlabs, Funkhaus Berlin, Germany). Provisional specimens to be tested will be fabricated by the Primary Investigator (PI, MAJ Daniel Bjorge) at the Schofield Barracks Dental Clinic Laboratory, Schofield Barracks, HI. Fracture testing will be conducted using a universal testing machine (MTS 858 Mini Bionix II Test System) by the PI supported by Lee-Ann Murata at the Department of Clinical Investigation (DCI) at Tripler Army Medical Center, HI. Method of data analysis has been performed by biostatistician, Mr. Michael B. Lustik.

Molar tooth preparation:
A Dentoform (Columbia Dentoform, New York, NY, USA) mandibular first molar tooth will be prepared for a full ceramic crown to the following specifications: 1.5 mm occlusal reduction, 1.0 mm axial reduction, and 1.0 mm round shoulder margin. A polysiloxane index (Lab-Putty, Cotene/Whaledent AG, Altstatten, Switzerland) will be formed to the unprepared typodont tooth confirm reduction dimensions and measured with a periodontal probe [11]. Convergence angle (Total occlusal convergence or TOC) will be approximated using a technique described by Yoon et al [12]. The prepared tooth taper convergence will be verified using a Canon EOS Rebel T3i camera and contrasting background at 30 cm from the tooth. The image will be used to estimate the degree of taper of buccal-lingual and mesial distal axial walls using an on-screen protractor

software (Aequo, Inc). The gingival 2mm of axial wall will be used to determine taper. Crown preparations with TOC values between 10-20 degrees allow for adequate retention and resistance form. An impression of a dentoform molar tooth prior to crown preparation will be made using a stock quadrant tray and vinyl-polysiloxane (Aquasil Ultra Heavy Body and Aquasil XLV, Dentsply Caulk, Milford, DE, USA). This matrix will be used for direct fabrication of provisional crowns.

Master die preparation:
The prepared typodont tooth will be embedded in type IV dental stone to the level of the CEJ. The stone housing will be formed cylindrical in shape (14mm in diameter x 24mm in height). A digital scan will be made of the stone imbedded typodont tooth using a labtop scanning device (Freedom HD, DOF, Seoul, South Korea) and an STL file made to fabricate duplicate master dies for fracture testing. Master dies will be printed using the STL file from above with a Formlabs SLA printer and Model V1 resin material (Formlabs, Funkhaus Berlin, Germany). The printed dies will be processed according to manufacturer's instructions.

Bis-acryl provisional crown fabrication:
The matrix as described above in the molar tooth preparation section will be used to fabricate chairside crowns using bis-acryl material, Luxatemp Ultra. The bis-acryl material will be placed into the matrix using a dispensing gun with an automix tip loaded and the matrix seated on the prepared dye with firm pressure. The sample restorations will be separated from the die and excess material removed gently with a carbide acrylic bur. The oxygen inhibited layer will be removed with alcohol and 2x2 gauze before finishing and polishing with a rag wheel and pumice. All restorations will be inspected under a dental laboratory microscope (Stereomicroscope S 300 II, G10XT, Kikuchi, Japan) for voids or defects. A digital caliper (General Tools, No. 1433, Secaucus, NJ, USA) will be used to confirm thickness and uniformity at buccal, lingual, mesial, distal and occlusal surfaces. Provisional crowns will be inspected for quality control to ensure voids are not introduced by operator error. Samples with voids, defects or insufficient thickness will be discarded.

CAD/CAM provisional crown fabrication:
CAD/CAM provisional crowns for both milled and 3d manufacturing will be designed with exocad designing software (exocad GmbH, Darmstadt, Germany) from scanned stl files produced with the same labtop scanning device used above. TelioCAD samples will be milled based on the exocad design proposal STL file with identical anatomy using a 5-axis milling unit (CORiTEC 350i, imes-icore, Eiterfeld, Germany) with 98.5 – 20mm Telio CAD pucs (Ivoclar Vivadent AG, Schaan, Liechtenstein). The Temporary CB Resin samples will be printed on a Form 3 SLA printer using the same STL file used to manufacture the TelioCAD samples(Formlabs, Funkhaus Berlin, Germany) and processed according to manufacturer instuctions. The TelioCAD and CB Resin samples will be inspected as described above and polished using a rag wheel and pumice.

Fracture strength test:
Crowns from all groups will be cemented to the printed master dies using TempBond NE automix syringe (Kerr, Orange, CA, USA) with a setting time of 7 minutes. All samples will be loaded into the universal testing machinev(MTS 858 Mini Bionix II test system, Eden Prairie, MN) in the same orientation with the force applied to the central pit of each sample. The universal testing machine will be used to apply a compression force at a crosshead speed of 1mm/min to each sample until failure. The force measured in newtons will be recorded as a data set over time, and the force value at failure will be recorded as the first distinguishable decrease in force identified in the data set.

The extent of fracture for each sample will be recorded based on a modified Burke's Classification.

1. Type I- Minimal fracture in crown
2. Type II- Less than half the crown
3. Type III- Crown fracture through midline, or half the crown displaced
4. Type IV- More than half of the crown displaced

Statistical Analysis:
Sample size justification: a sample size of 25 for each material type (alpha=0.05) will allow the study to have 80% power to detect a 184 Newton difference between direct fabrication and the two modes of CAD/CAM fabrication. This assumes a standard deviation of 200.

Data analysis: analysis of variance (ANOVA) will be used to assess differences in mean fracture strength and endurance limit among the three different materials and fabrication methods. Nonparametric Kruskal-Oalls and Wilcoxon rank sum tests will be used to compare fracture patterns based on Burke's 4 category classification. Fracture pattern data may also be dichotomized and analyzed by chi-square or Fisher's exact tests. A significance level of 0.05 will be used for all analyses.

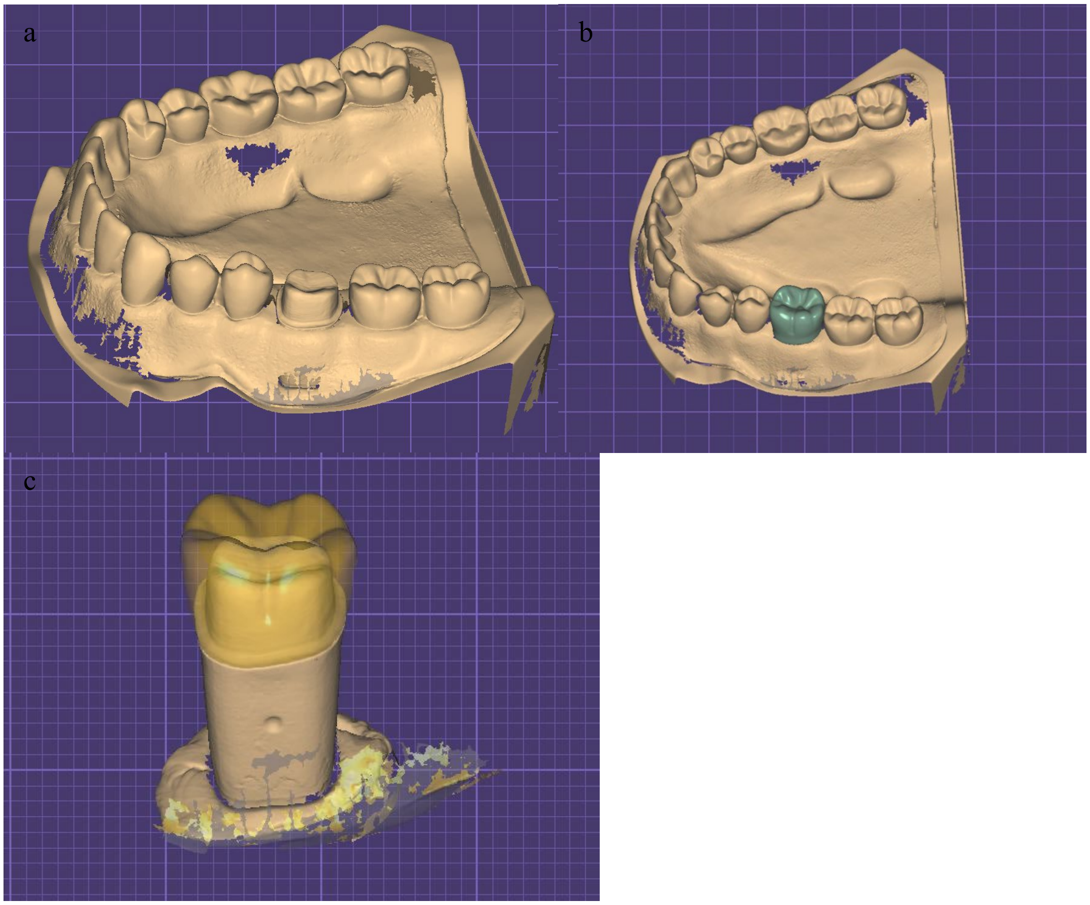

Figure 1. a-c: Digital workflow to design STL of crown for Telio CAD and CB Resin crown fabrication.

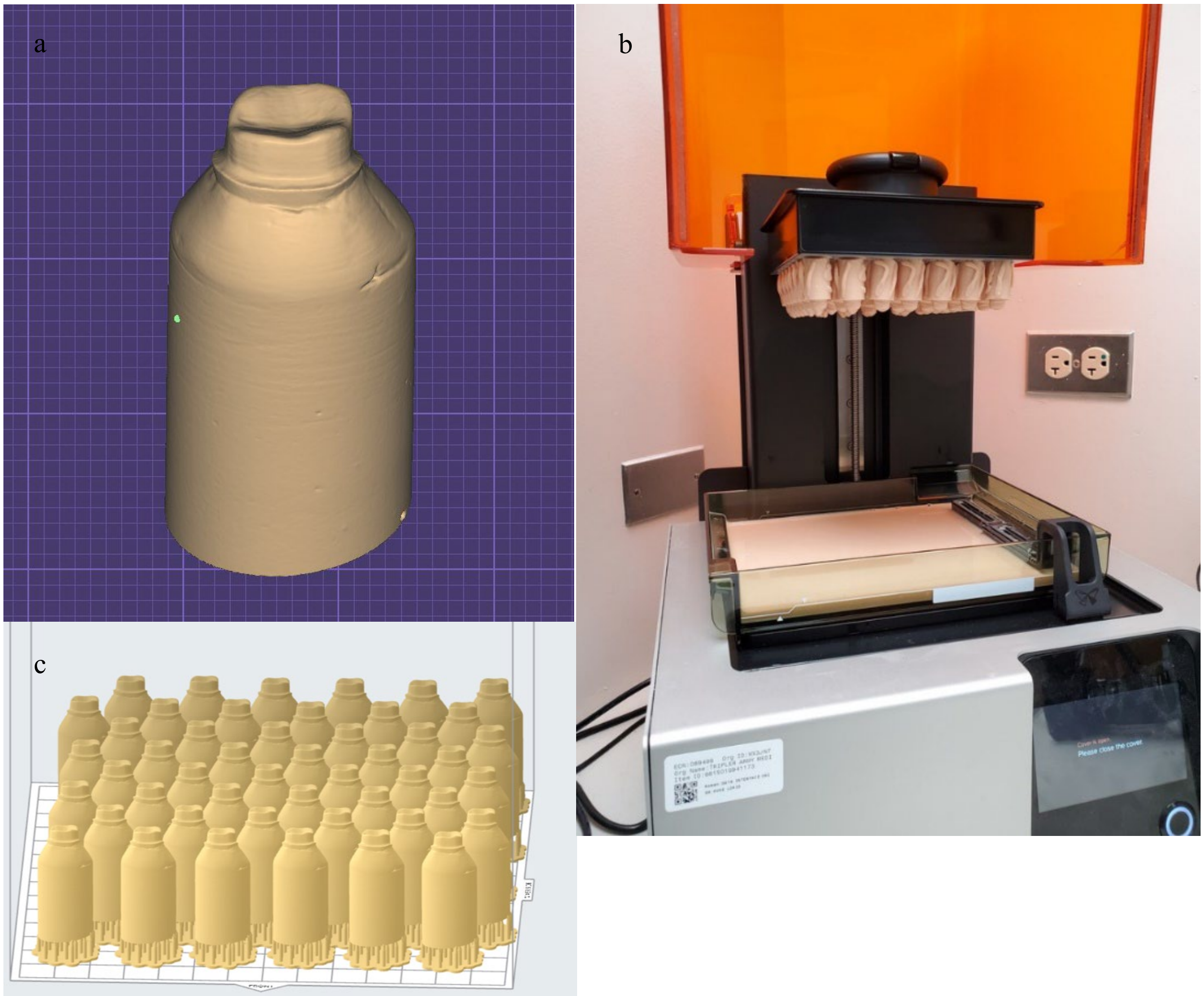

Figure 2. a-c: Digital workflow for fabrication SLA (3-D printed) dies (Image c credit to MAJ Migdalia Torres).

Figure 3. Provisional crowns cemented to SLA fabricated dies (Photos credit to MAJ Migdalia Torres).

Type I- Minimal fracture in crown
Type II- Less than half the crown
Type III- Crown fracture through midline, or half the crown displaced
Type IV- More the half the crown displaced

Table 1: Modified Burke's classification of fracture pattern.

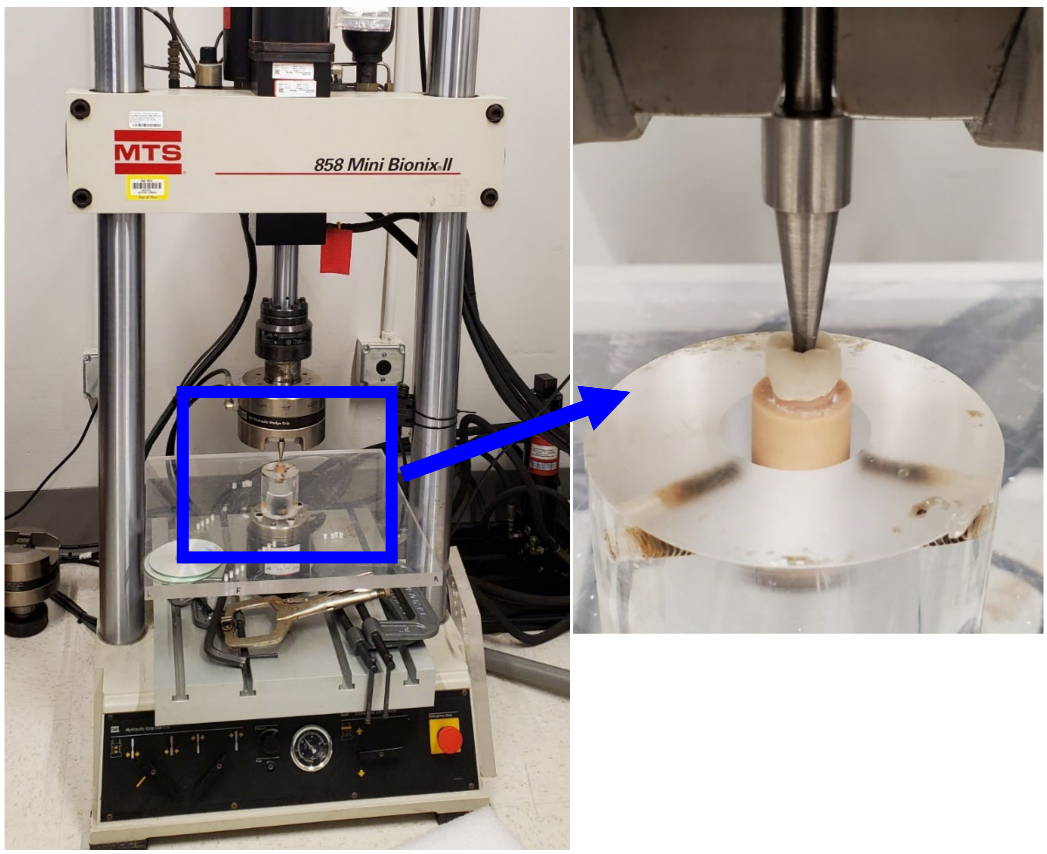

Figure 4. Specimen mounted on Universal Testing Machine (Photos credit to MAJ Migdalia Torres).

RESULTS:

Results: The force to failure in newtons for each group (Mean ± SD) were 2702 ± 354 for TC, 2254 ± 347 for LT, and 2334 ± 456 for CB. Fracture strength of TC was significantly greater than those of LT and CB $p<0.01$. Higher force was required to create complete fracture, (fracture pattern 4), than the other modes of fracture ($p<0.01$), and TC was more likely to fail in this manner at a rate of 60% compared to 36% and 32% for Materials CB and LT respectively.

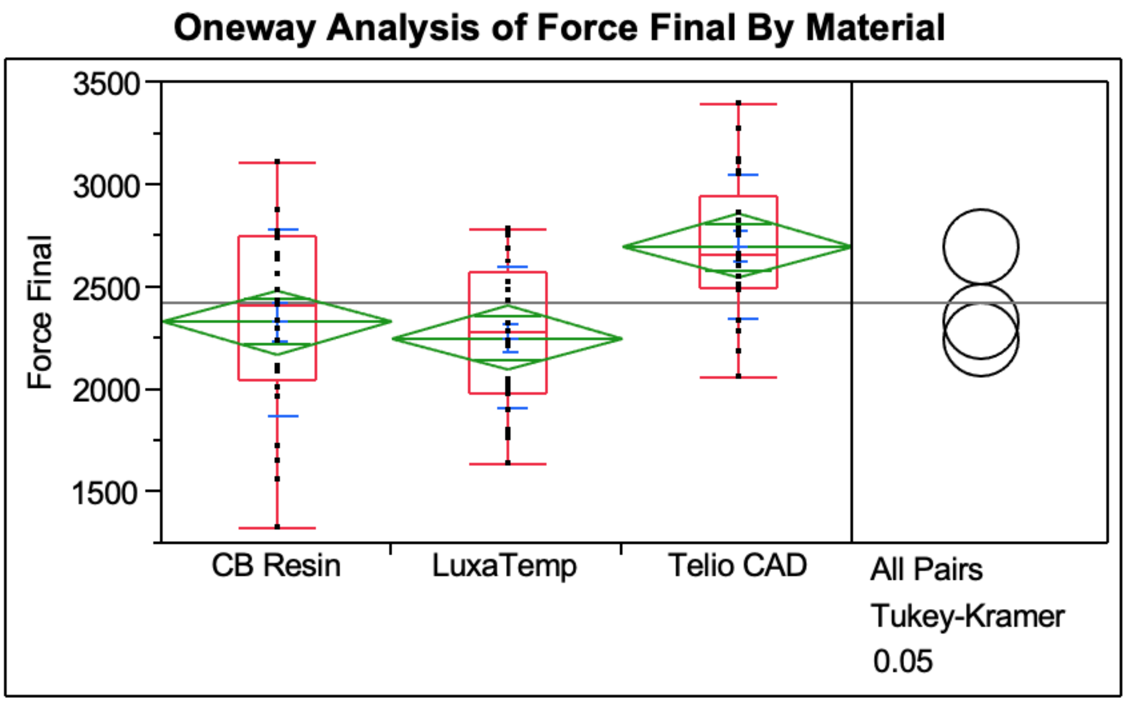

Figure 5: One way analysis fracture strength of provisional crowns. Telio CAD was significantly stronger than CB Resin and Luxa Temp ($p < 0.01$).

Material	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
CB Resin	25	2334	456	91	2146	2523
Luxa Temp	25	2255	347	69	2112	2398
Telio CAD	25	2702	354	71	2555	2847

Table 2. Overview of fracture strength of CAD/CAM and bis-acryl provisional crowns means and standard deviations.

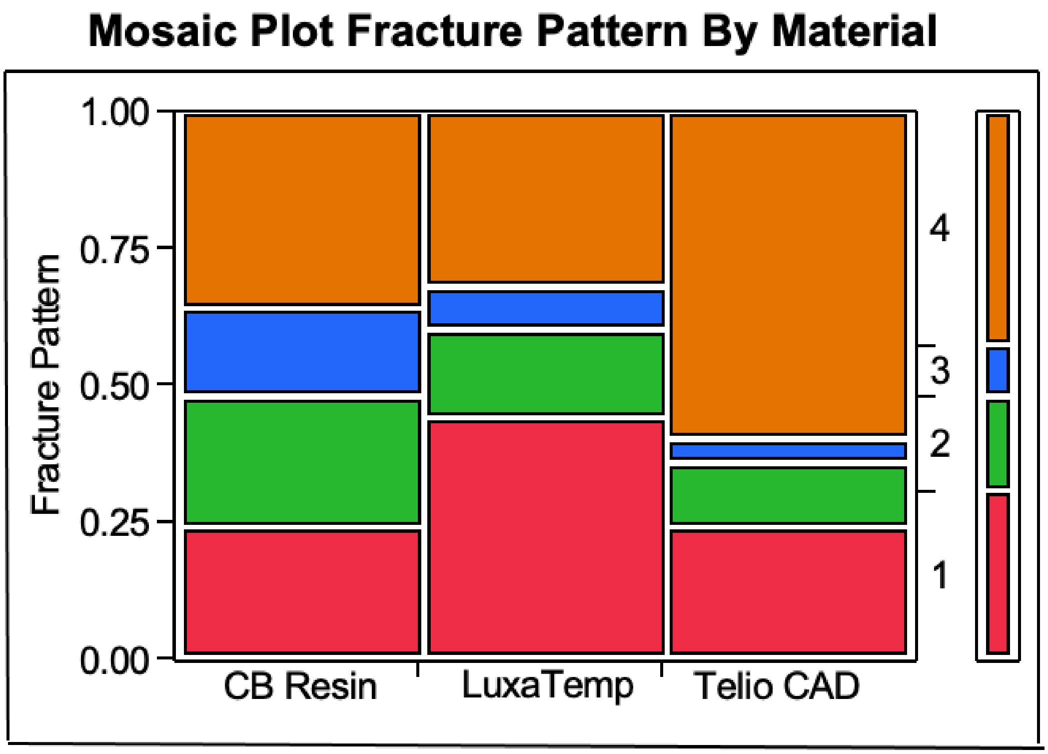

Figure 6. Mosaic plot representing fracture pattern by material. There was no significant difference in fracture pattern by material.

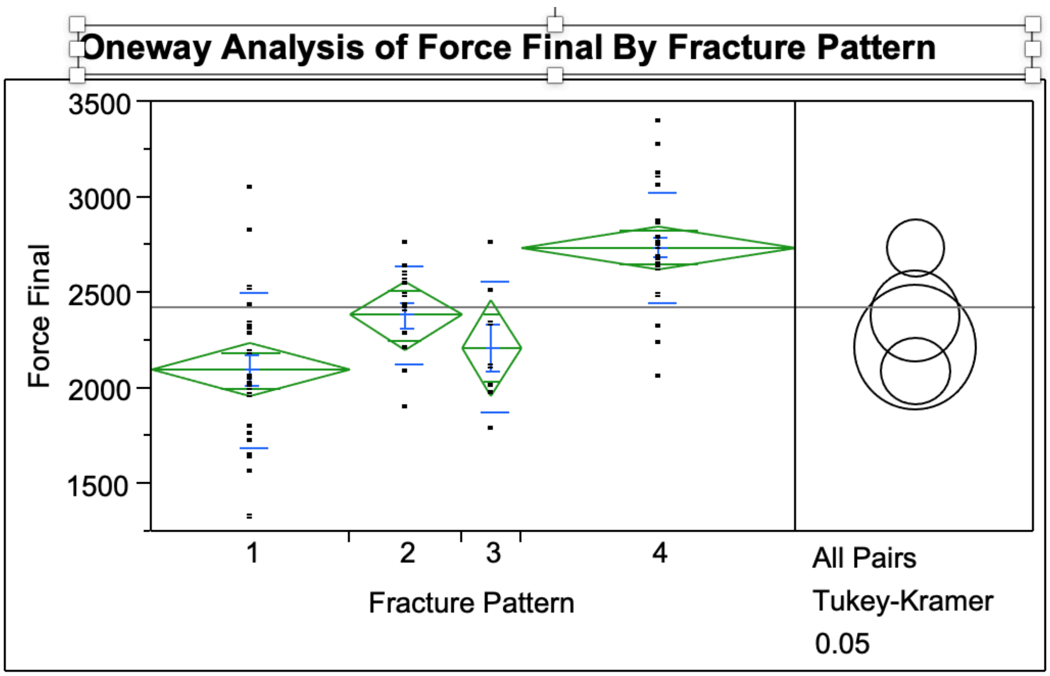

Figure 7. Oneway analysis comparing fracture pattern by final force in newtons means.

Fracture Pattern	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
Type I	23	2096	409	85	1919	2273
Type II	13	2385	255	71	2231	2539
Type III	7	2214	342	129	1898	2531
Type IV	32	2736	292	292	2631	2842

Table 3. Comparison of Fracture Type with respect to final force in newtons means and standard deviations.

DISCUSSION:

Three dimensional printed materials for use as temporary dental restorations is still a very new concept and have only recently been FDA approved for long-term intraoral use. Companies like BEGO and Form Labs now boast printed resin materials for use as both provisional and permanent dental restorations. As these materials have only been commercially available for the last couple years, there is understandably little in the way of data comparing this new material to more contemporary materials used for fabrication of provisional crowns.

In this study we had to reject the null hypothesis that there was no difference in fracture strengths between the three provisional materials tested. It is well documented that chairside bis-acryl materials do not offer the same strength characteristics as milled PMMA materials. This study found that CB was stronger than LT, but this difference was not statistically significant. The TC material was stronger than both CB and LT materials and this difference was statistically significant. These findings do seem to be in agreement with the study done by **Digholkar et. al.**, which found that printed resin material's flexural strength does not meet or exceed that of conventional bis-acryl or PMMA materials [8]. The material advantages Telio CAD and similarly manufactured materials can boast is that these are monolithic blocks or discs that were processed industrially to maximize material homogeneity and degree of polymerization. The fact that chairside and printed materials have less environmental processing control during polymerization may put them at a disadvantage comparatively.

The CB resin crowns fractured with the greatest degree of variation as can be seen on Table 2. This observation was not statistically significant but does speak to the complexity involved with the post-processing steps for the CB crowns. Printed crowns require supports which are spread across one surface of the crown; these supports must be removed and the crowns subsequently polished after a second period of curing. In removing the supports, the author's observational findings were that supports do break away and some of those remove excess material from the exterior surface of the crown. Furthermore, supports need to be removed with an acrylic bur by hand, and there was opportunity for an excess of material removed inadvertently from the outer surface of the crown. The other materials tested did not require any structural adjustment to the occlusal surface of the crown, so those crowns were more dimensionally identical to one another than the printed crowns.

Fracture pattern for the TC group was type IV 60% of the time and was more likely to fracture with this pattern than the other two materials which observed type IV fractures occurring 36% and 32% for CB and LT respectively. There was no statistical difference in the fracture patterns when comparing the materials to one another; however, there was a statistically significant correlation that could be made to fracture pattern IV and force at crown fracture. Fracture pattern IV occurred more frequently when the sample was under more force at fracture which may explain the increased incidence of type IV fracture in the TC group.

While this study did achieve results that were statistically significant, there were some limitations to the study that should be pointed out. The dies were placed in the testing machine with the intent to have the point of impact at the central pit of the clinical crown for each sample tested. Unfortunately, the author did not have any means to ensure that the contact point was at precisely the same position for each sample. The use of a jig or other means to ensure identical positioning of the samples into the testing machine could offer more precision to the study. The samples were all cemented to dies by hand and no means to ensure identical pressure applied to each sample which may lead to variability in cement layer thickness within groups. Cement layers between groups were also variable due to differences in the fit of sample crowns to dies between groups. The CAD/CAM crowns were manufactured using the same STL file; however, the CB crowns fit more tightly to the dies compared to the TC crowns. In some cases CB crowns required relieving of the intaglio surface of the axial walls to allow for complete seating onto the die, whereas all of the TC crowns fit smoothly over the die. The LT crowns all fit snugly to the die but were all capable of complete seating without alteration of the intaglio surface of the crown.

A follow-up study investigating the dimensional stability of printed crowns relative to the STL file prescription may be warranted. There was sufficient shrinkage to impede complete seating of samples in this study even with a cement space incorporated into the design of the crown. It may be necessary to incorporate a compensatory expansion of the restoration in the design of the crown.

CONCLUSION:

Fracture strength was significantly greater for TC compared to the other materials tested, and there was no significant difference in fracture strengths between CB and LT. Given the post-manufacturing processing disadvantages and fracture strength characteristics of CB crowns, Telio CAD would be a more ideal material choice for long-term provisional crowns and fixed dental prostheses. Printed materials, like the one studied here, will likely improve rapidly as 3D printing of dental restorative materials is an emerging market. More studies will need to be done as improvements are made in 3D printed dental materials.

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