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Clinical Performance of 3D-Printed Provisional Dental Crowns: Pilot Study

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Novel 3-D printed provisional dental crowns show promising characteristics in laboratory studies that are similar to or better than traditional provisional crowns. As of this time there are no clinical studies comparing printed crowns to traditional directly fabricated crowns. Objective: The purpose of this study is to evaluate the short-term clinical performance of a 3D-printed provisional crown (Temporary CB, Formlabs) compared to a traditional direct provisional crown (Integrity®, Dentsply Sirona). Methods: Each patient received a Temporary CB and an Integrity® provisional crown on separate teeth opposing minimally restored natural teeth. Qualitative analysis was completed using the FDI World Dental Federation criteria for evaluation of restorative materials at the time of placement and at least three months after wearing the provisional crowns. Quantitative wear analysis was completed by superimposing digitally scanned baseline and 3-month images and quantifying the wear using spatial analysis software (Geomagic Freeform®, 3D Systems, Rock Hill, SC). Results: One patient was evaluated for 3-months. Clinically acceptable results were noted within both material groups. The volumetric wear for the Integrity® and Temporary CB crowns were 4.2 mm^3 and 0.44 mm^3 respectively. Conclusion: After 3-months, less wear was noted with the Tempoary CB material. However, it was noted that the baseline shade of the Temporary CB crown showed a difference in a darker shade compared against a VITA classical shade guide (VITA North

America, Yorba Linda, CA). Although the shade was initially darker, it remained stable during the 3-month evaluation period. The printed crown fabrication time, for the Formlabs system, took too long for same-day crown delivery.

Key words: 3D-printing, provisional, additive manufacturing, CAD/CAM, digital dentistry

Introduction

Provisional crowns are regularly used for temporary support during definitive prosthetic manufacturing, emergent care, pre-prosthetic planning, physiological management [1], and prosthetic rehabilitation [1-4]. The provisional restoration must be able to withstand extensive loading forces, temperature changes, moist environments, and occasionally survive for long periods of time [1]. Additionally, it must be biocompatible with human tissue and be esthetically acceptable [1, 3, 5].

Trauma, restoration fracture, tooth fracture, or restoration dislodgement may compromise the remaining tooth structure, pulp vitality, surrounding gingival tissues, and adjacent or opposing teeth[1]; and transition to a full coverage restoration may be indicated [3]. Interim coverage of a tooth can be completed directly or indirectly [1]. According to a study by Crispin et al., indirect methods of fixed prosthesis fabrication can produce better margin adaptation by 70% compared to direct methods [6]. In a military deployed setting, a dentist has limited resources to fabricate a provisional crown indirectly and is often required to utilize direct methods.

There are disadvantages to direct methods of fabricating a provisional crown. Stress of inserting and removing a provisional crown during fabrication may lead to crack initiation and propagation [7]. Increased fracture propagation can reduce the restoration

longevity [1, 7]. Marginal adaptation of directly fabricated provisional restorations have been shown to be less favorable than indirect methods [1, 8]. Direct fabrication also requires increased chair-time [8]. Additionally, gingival recession [9] and contact stomatitis [1] are potential side effects of direct methods.

Novel computer aided design (CAD) and computer aided manufacturing (CAM) methods could provide a practical means for indirect fabrication of provisional crowns, particularly in limited supported deployment facilities. A CAD/CAM generated provisional can be less labor-intensive, may require less fabrication time, and may introduce fewer errors than manual indirect fabrication methods [3, 10-12]. Subtractive CAD/CAM provisional fabrication methods, such as a milling procedure, have been popularized [13] in the last two decades and could provide support in deployed locations but are still costly [3] and many require specialized equipment (e.g. installation and calibration), plumbing, electrical, compressed air, and maintenance support that may not be practical in more austere environments. Additive CAD/CAM technology, such as 3D printing, has a smaller footprint, is less expensive [3, 11], wastes less material [3], is better at fabricating complex shapes, is more precise [3, 10, 12], and does not come with complex utility and maintenance requirements of subtractive CAD/CAM technology.

Recently, the FDA has given clearance to many 3-D printing manufacturers for resins that can be used for provisional crowns [3]. In-vitro studies of these materials have demonstrated structural characteristics that are comparable to and in some respects preferred to conventional provisional restorative materials [3, 7]. To our knowledge there have been no in-vivo studies conducted on an additive provisional CAM restoration.

We wanted to discover how well a new additive provisional material performs in the oral environment compared to a material that is commonly found at deployed locations. The test material was Temporary CB Resin (Formlabs, Somerville, MA). This material was selected because it is compatible with the Formlabs 3B/3B+ printers (Formlabs, Somerville, MA) that are commonly used in military dentistry today, but not at deployed locations. Formlabs partnered with BEGO (Bremen, Germany) to make Temporary CB Resin [14]. BEGO sells the same product under the name VarseoSmile Temp. It contains esterification products of 4,4'-isopropylidiphenol, ethoxylated and 2-methylprop-2enoic acid, silanized dental glass, and methyl benzoylformate, diphenyl (2,4,6-trimethylbenzoyl) phosphine oxide. Its total content of inorganic fillers (particle size 0.7 µm) is 30–50% by mass [15]. The comparison material selected was Integrity® (Dentsply Sirona, Charlotte, NC). Integrity® is a bis-acryl resin [16] and contains barium glass, fumed silica, methacrylate monomers, catalyst, and stabilizers [17]. Integrity® was selected because it is one of the most common direct provisional materials used in military dentistry, is currently used in deployed locations, and has acceptable material properties [1] for provisional crown fabrication.

The purpose of this study was to evaluate the short-term clinical performance of a 3D-printed (Temporary CB) indirect provisional crown compared to a traditional direct provisional crown (Integrity®). The null hypotheses were there will be no differences in the clinical criteria or volumetric wear between the indirect and direct provisional restorations after three months of clinical use.

Methods

Two provisional crown materials (Formlabs Temporary CB Resin and Dentsply Sirona Integrity® Temporary Crown & Bridge Material) of the shade A2 were evaluated for this study. The study participants were selected from patients enrolled in the Advanced Education of General Dentistry (AEGD) 2-year program at Joint Base San Antonio (JBSA) Lackland, Texas. The sample size was selected based on power analysis to detect a moderate effect size difference in means of 0.50 using a two-sided paired t-test. Based on a power percentage of 80%, 34 pairs of teeth would be needed. Forty-two subjects were requested for the study to account for any loss of participation in the study. However, only one case has been completed at this time due to the complexity of starting the study.

Patients were screened according to their medical and dental history. The selection of subjects for this clinical study was based on a diagnosed need for at least two full coverage tooth-supported single crowns. The inclusion criteria was: (1) teeth needing treatment opposing minimally restored natural teeth; (2) 18 years of age and older, with good oral and general health (good general health indicated by an ASA classification I or II); and (3) able to return for definitive treatment after three months. The exclusion criteria was root canal treated teeth. This study was approved by the San Antonio IRB and study participants completed informed consent and HIPPA documents prior to participating.

Tooth preparations were made with smooth, round contours and angles, modified shoulder finish lines at least 0.8 to 1 mm deep with round internal angles, and occlusal reduction with at least 1.5 mm. Pre-molar axial wall heights were at least 3 mm and molar axial wall heights were at least 4 mm. After tooth preparation, a dual-arch digital scan was

made using a chairside digital scanner (Medit i700, Medit Corp, Seoul, Korea), (Figure 1). The type of provisional material was randomized such that one tooth received a directly fabricated provisional restoration and the other received a 3D-printed restoration.

To reduce provisional crown form bias, both the indirect and direct provisional crowns were designed using CAD software (Exocad, Align Technology, Tempe, AZ). Also, to prevent the evaluators and patient from knowing which tooth would receive a printed provisional crown, printed provisional crowns were fabricated for both teeth and given to the dental provider in addition to a provisional matrix (Figure 2). Two crowns were printed for each tooth to account for any accidental over reduction by the dental provider at the time of fitting the crowns. This was done because the total print and post processing time was two hours, and the manufacturer did not provide instruction on how to add to a crown contact if over reduced. The printing of four crowns, versus one crown, did not increase the printing time—only the finishing and polishing time were affected.

After provisional crowns were designed using the above-mentioned CAD software, the designs were transferred to a print-preparation software (PreForm, Formlabs, Somerville, MA). The crowns were fabricated using the Formlabs Temporary CB Resin on a Formlabs 3B+ printer (Formlabs, Somerville, MA) following the manufacturer's instructions [18] and printed in 50 µm layers. The printed crowns were processed according to the manufacturer's instructions utilizing a 3-minute 99% isopropyl alcohol automated wash (Form Wash, Formlabs, Somerville, MA) and two automated post-curing (Form Cure, Formlabs, Somerville, MA) cycles at 60°C for 20 minutes each. In addition, a model of the prepared teeth was printed. The printed crowns were fit to the printed prepared teeth and a provisional matrix was made from the printed prepared teeth for the

indirect provisional crown using 0.04-inch vacuum formed material (Essix ACE Plastics, Dentsply Sirona Orthodontics, Sarasota, FL). On one case, a putty matrix (Aquasil Ultra+, Dentsply Sirona, Charlotte, NC) was made (Figure 2) in addition to the vacuum formed matrix and both were used to make an indirect provisional crown and compared. The dental provider reported more occlusal adjustments were necessary when using the putty matrix as compared to the vacuum formed matrix. All future provisional matrixes were made using only the vacuum formed matrix.

A virtual coin flipping application (Coin sim, Scripto Industries) was used at the time of provisional crown delivery to determine which tooth received the printed crown. The dental provider fabricated the Integrity® provisional crown chairside following manufacturer instructions and finished the restoration using a finishing and polishing system (Enhance, Dentsply Sirona, Charlotte, NC). Final finishing and polishing of the 3D-printed restorations were completed using the same finishing and polishing system (Enhance, Dentsply Sirona) used for the Integrity® provisional crowns. Both provisional crowns were cemented using a provisional cement (Durelon™, 3M™, St. Paul, MN). The occlusal contacts of the crowns were adjusted to maximum intercuspation with no lateral excursive contacts to account for differences in study participant's occlusal schemes and anterior guidance. A second dual-arch scan was captured and represented T_0 as a control from baseline.

Clinical evaluations of the provisional restorations were completed at baseline and at three months using a double-blind assessment method. Neither the patient nor the assessors had prior knowledge of which materials were used during treatment. Two experienced clinicians examined the provisional restorations after training and calibration

to minimize inter-examiner variability. The Cohen's Kappa was planned to be used as a statistical measure of inter-examiner reliability for the categorical variables, but only one case has been completed at this time. The assessors were trained to score the completed restorations using a modified FDI World Dental Federation criteria for evaluation of restorative materials [19]. The modified FDI criteria was utilized at baseline to evaluate the provisional crowns for esthetic, functional, and biologic properties as outlined in Tables 1-3. After three months, the subject returned to the clinic for a final dual-quadrant scan and clinical re-evaluation of the provisional crowns using the modified FDI criteria and insertion of the permanent crowns. All clinical evaluations were performed using standardized dental diagnostic instruments and visual inspection with the aid of magnification (x2.5-5.5) (EyeZoom; Orascoptic, Madison, WI) with standard dental unit and overhead lighting.

Quantitative analysis of wear was performed by superimposing digitally scanned baseline and 3-month images and quantifying the wear using spatial analysis software (Geomagic Freeform®, 3D Systems, Rock Hill, SC). Volumetric wear (mm^3) was determined for the provisional restorations.

The categorical data (FDI criteria) was compared between the two provisional materials, but the planned analysis using non-parametric statistics (Wilcoxon Signed-Rank test) and descriptive statistics such as mean and standard deviation and inferential statistics, such as paired T-test, to analyze the continuous wear data between the two provisional materials ($\alpha=0.05$) was not used because only one case has been completed at this time.

Results

A total of four restorations were placed in two participants. Two restorations were the Integrity® directly fabricated crowns and two restorations were the indirectly fabricated Temporary CB printed crowns. Only one of the two cases has been completed at this time and only results from the completed case will be presented. Volumetric analysis was accomplished for the one completed case. The qualitative data obtained for volumetric wear was a function of the surface area of occlusion in mm^3 units. The volumetric surface loss for the Integrity® crown and the 3D-printed crown was 4.2 mm^3 (Figure 3) and 0.44 mm^3 (Figure 4) respectively. Based on this one completed case, there was more volumetric wear of the Integrity® crown compared to the Temporary CB printed crown.

Of the 11 FDI criteria evaluated at the baseline there were only two criteria that differed between the Integrity® crown and the Temporary CB printed crown. These differences are seen in Table 4. The Integrity® crown showed a better color match (Figure 6) to a VITA classical A2 shade tab (VITA North America, Yorba Linda, CA) than the Temporary CB printed crown. The Temporary CB Resin A2 printed crown best matched the VITA A3 (VITA North America, Yorba Linda, CA) shade tab at baseline. The Temporary CB printed crown showed better anatomical form than the Integrity® crown.

Both crowns were retained during the 3-month evaluation period (Figure 6 and 7) and no fractures occurred. However, the tooth #18 Integrity® crown (Figure 7) dislodged twice during the 3-month period and had to be re-cemented. The first time the #18 provisional crown dislodged was due to the patient eating sticky food and the second time, the patient reported he accidentally flossed the crown off. Re-cementation of the

#18 provisional crown followed the same cementation protocol previously mentioned in the methods and materials section and was re-cemented within 24 hours of dislodgement.

Of the 11 FDI criteria evaluated at the 3-month final evaluation there were 6 criteria that differed between the Integrity® crown and the Temporary CB printed crown. These differences are seen in Table 5. The Integrity® crown showed better marginal adaptation and a better interproximal contact point while the Temporary CB printed crown showed better surface staining resistance, color stability, and anatomic form.

Discussion

No clinical or laboratory studies could be found comparing the wear of Temporary CB printed crowns to Integrity® crowns, but a 2021 in-vitro study by Myagmar and colleagues[3] found less volumetric wear of a temporary 3D-printed crown (NextDent C&B, NextDent, Soesterberg, Netherlands) compared to a directly fabricated PMMA provisional (Jet™, Lang Dental Manufacturing, Wheeling, IL, USA). In the Myagmar study, the provisional crown specimens were subjected up to 3-months of simulated chewing cycles (60,000). The mean material loss in mm^3 units was 0.1 for the printed (Next Dent C&B) crowns and 0.44 for the conventional provisional crowns (Jet™). Our results showed a much greater difference between the wear of the printed provisional (0.44 $mm^{3)}$ and the conventional provisional (4.2 mm^3). Reasons for this greater loss could include the Integrity® crown (tooth #18) being positioned in the mouth more posteriorly than the Temporary CB crown (tooth #13), outcomes of re-cementing the #18 crown, using an intra oral scanner (Medit i700) versus a confocal laser scanning microscope (LSM 800 MAT, Zeiss, Jena, Germany) that was used in the Myagmar study,

errors in preparing files for analysis using Geomajic software, or the results demonstrate the actual wear of the materials during the 3-month period.

Care was taken during the initial and re-cementing procedures to idealize the occlusal contacts in maximum intercuspation with no lateral excursive contacts to account for differences in study participant's occlusal schemes and anterior guidance. Occlusal contact was verified with one shimstock (Shimstock Strips 12μ, Almore International, Beaverton, OR) hold and no shimstock contact in excursive movements. During the re-cementation of tooth #18 provisional crown no occlusal adjustments were necessary to obtain the above-mentioned occlusal contact. Although care was taken to idealize occlusion in maximum intercuspation, it cannot be ruled out that there could be differences between centric occlusion and maximum intercuspation. Differences between centric occlusion and maximum intercuspation could introduce unfavorable occlusal wear especially if tooth #18 was a first tooth contact and incorporated interfering contact when going into maximum intercuspation.

The accuracy of the Medit i700 scanner has been tested in in-vitro and in-vivo studies and has shown similar or better accuracy, in tooth-born areas, to other current intra-oral scanners on the market [20-23]. However, there are no known studies of the accuracy of using the Medit i700 scanner for measuring tooth wear. In a study conducted by Mitrirattanakul and colleagues (2023), the intraoral scanner (iTero Element® 2, Align Tech., Inc) accuracy was compared to a micro-CT scanner (SkyScan 1173, Bruker) in detecting volumetric wear [24]. The Mitrirattanakul study showed the intra-oral scanner was 97% as accurate as the micro-CT scanner in measuring tooth wear. It is assumed the Medit i700 scanner would have similar results based on a previous study showing the

Medit i700 scanner has similar accuracy to the iTero Element® scanner [21] but further research is warranted.

Software analysis of the volumetric wear required overlaying the baseline scan with the 3-month final scan. The software used auto-aligning technology to best fit the two scans (Geomagic Freeform®, 3D Systems). Auto-aligning is best performed with full arch scans to increase the number of connection points. Only quadrant arch scans were provided for wear analysis. Quadrant arch scans were made during evaluation because Medit i700 has shown better scanning accuracy with quadrant scans compared to full arch scans [23]. There are no known studies comparing the accuracy of overlaying full arch versus quadrant arch scans when conducting volumetric wear analysis. It is assumed that the difference between full arch and quadrant arch overlaying would be on a micrometer or less scale and would not have a significant influence on the millimeter scale that was used in this study.

The re-cementation of the #18 crown may have introduced errors in the software volumetric analysis during the overlaying process. Because the #18 re-cemented crown may have been in a slightly different position compared to the initial scan, the overlaying algorithms may have used points from the #18 crown during the overlaying process. To verify movement of the crown after re-cementation, wear scans taken directly after re-cementing the crown would have been useful. New scans were not taken after re-cementation of the #18 crown to verify its position. For future studies it is recommended to re-scan any dislodged crowns after re-cementation.

There were differences noted between examiner initial findings and 3-month findings that had contradictory results. For the completed case, the examiners at the initial

evaluation had noted the printed crown on tooth #13 had a light distal contact when testing with floss, but decided it was not of clinical relevance and scored the “contact point/food impact” criteria a 1 out of 5 in the FDI evaluation scale. At the 3-month evaluation the examiners noted the same finding but accounted for it and scored it a 3 out of 5 because a score of 2 suggested a contact that was too tight and a score of 3 suggested a contact that was slightly too weak. By not indicating the light contact at the time of initial evaluation, the comparison between the initial and final evaluation made it appear the contact progressively worsened over time in the amount of 2 criteria points. This difference could wrongfully impact future analysis. Similarly, during the initial evaluation the examiners noted the #13 crown had a slight margin discrepancy with a horizontally over extended margin. Within the margin evaluation criteria, there were no scores for horizontal margin discrepancies, so the examiners scored the criteria a 1 out of 5. At the 3-month follow-up, the examiners decided to account for the over-extended horizontal discrepancy and scored it a 2 out of 5. This score would suggest the margin worsened over time, but it was a result of not having clear criteria to select from and the examiners trying to find ways to account for findings that are not clearly defined in the evaluation form. It has been suggested the evaluators have access to the original baseline evaluation forms with previous notes to avoid unintended contradictory scoring. Also, it has been suggested the evaluators receive additional training and calibration to clear-up the nuances of scoring that have been discovered since evaluations have been conducted.

The fabrication of the printed crowns took longer than expected and required a return appointment for delivery of the provisional crowns. Crown printing took an average

of 45 minutes. The speed of a print for the Formlabs 3B+ printer was a function of the number of layers that needed to be printed. The number of crowns printed at one time had little impact on the print speeds. The Preform (Formlabs) proprietary slicing software only allows a printing thickness of 50 μm when using Temporary CB resin. Being able to increase the layer thickness to 100 μm would reduce the print time by 50%. The isopropyl alcohol washing time of 3 minutes had little effect on fabrication time except the manufacturer recommended the printed crown evaporate the alcohol for at least 30 minutes prior to post-curing unless compressed air drying was available. The 30-minute wait time would drastically impact fabrication time if compressed air was not available. Two curing cycles in the Form Cure (Formlabs) of 20 minutes each did drastically impact the fabrication time. The total fabrication time including designing, printing, washing, post-curing, support removal, finishing, and polishing was greater than 2.5 hours. Because the fabrication time took longer than expected, providing same-day printed crowns did not work in our clinic condition and conventional provisional crowns were placed on both teeth until the patient could return for placement of the printed crown and a re-make of the conventional provisional crown.

Other 3D-printers on the market have different technologies, accessories, and post-processing systems that reduce printing and post-processing time—making it more feasible for same-day printing. Ackurretta, the creator of the Sol 3D-printer (Taipei, Taiwan) boasts a single crown print time of 15 minutes [25]. Ackurretta uses faster printing technology, allows control of layer thickness, and has an option for a smaller build-plate size. These features allow for faster print times. Ackuretta's post-processing protocol and equipment further reduces fabrication time totaling a design to insertion time of 50

minutes [26]—almost 60% faster than the Formlabs printing solution. Studies of other printing solutions are warranted and should be looked at when considering 3D-printer acquisition for deployed locations.

It was anticipated this study would extend beyond one residency class due to the complexity of the inclusion criteria, 3-month follow-up, and IRB approval. It was not expected that the IRB approval process and supply acquisition would take as long as it did. During the IRB approval process, the 59 MDW IRB transitioned to the San Antonio IRB. This process resulted in substantial delays. It took a total of 9 months for the IRB approval. There were also delays in acquiring the equipment and supplies for this study. After IRB approval, it took 5 months to receive the core equipment to begin training the investigators on the use of the equipment. It took one month to train the investigators on equipment use, and the final supply item did not arrive until 8 months after the IRB approval. These delays drastically impacted our ability to begin enrollment of subjects in this study.

In addition, enrollment of study subjects proved more difficult than expected. The inclusion and exclusion criteria greatly impacted the ability to find study participants—causing further delays. Of the individuals evaluated who needed at least two posterior crowns, over 60% of them did not meet the inclusion criteria of the teeth opposing only minimally restored teeth and of those groups 30% of the subjects were excluded because they had root canal treated teeth. Only two study participants were found and enrolled in the study before it was determined the inclusion and exclusion criteria would need to be changed to find enough study participants to complete the study within the next residency class.

The proposed protocol changes by the incoming primary investigator are to include a single posterior tooth needing a crown and change the provisional crown material at 2-months on the same tooth. This design change will increase the total follow-up time by 1-month compared to the current protocol, but greatly increase the amount of study participants who could be included in the study. With this proposed change, it was decided to stop enrollment of the current protocol because data from the current protocol would not be compatible with the proposed study design for future analysis. Of the two subjects enrolled under the current protocol, one has been completed, and one will be completed in the coming weeks. The lessons learned from the current study design and results of the single completed case will be presented as a pilot study.

Conclusion

This study showed, for a duration of 3-months, a Temporary CB printed crown has clinically acceptable esthetic, function, and biological properties. The Temporary CB crown showed less wear than the Integrity® crown during a 3-month period, showed better color stability, and better anatomic form, but showed excessive horizontal crown margins, and did not have a manufacturer recommendation for adding to over-reduced contacts.

Though clinically acceptable, the printing process took longer than desired for same-day provisional crown delivery (2.5 hours). This may or may not be a problem in a deployed environment, considering current indirect restorative solutions would require shipping from distant locations.

Due to only a single data point, further research is needed to evaluate clinical performance of a 3D-printed (Temporary CB) indirect provisional crown. In future

research, it is recommended to consider changing the inclusion and exclusion criteria to allow for more study subject enrollment and to rule-out the confounder of tooth position by using the same tooth for evaluation of both materials. It is also noted that clarifying the FDI criteria in some scoring sections would allow for better categorical data comparison.

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Table 1: Esthetic properties (FDI Criteria)

A. Esthetic properties	**1. Surface luster**	**2. Surface staining**	**3. Color stability**	**4. Anatomic form**
1. Clinically excellent/ very good	1.1 Luster comparable to enamel	2.1 No surface staining	3.1 Good color match. No difference in shade	4.1 Form is ideal
2. Clinically good (after polishing very good)	1.2 Slightly dull, not noticeable from speaking distance	2.2 Minor staining, easily removable	3.2 Minor deviations	4.2 Form is only affected
3. Clinically sufficient/ satisfactory (minor shortcomings, no unacceptable effects but not adjustable w/o damage to the tooth)	1.3 Dull surface but acceptable if covered with film of saliva	2.3 Moderate surface staining, also present on other teeth, not esthetically unacceptable	3.3 Clear deviation but acceptable. Does not affect esthetics	4.3 Form differs but is not esthetically displeasing
4. Clinically unsatis-factory (but reparable)	1.4 Rough surface, simple polishing is not sufficient. Further intervention necessary	2.4 Surface staining present on the restoration and is unacceptable; major intervention necessary for improvement	3.4 Clinically unsatisfactory	4.4. Form is affected and unacceptable esthetically. Interven-tion (correction) necessary
5. Clinically poor (replacement necessary)	1.5 Quite rough, unacceptable plaque retentive surface	2.5 Severe staining and/or subsurface staining (gene-ralized or localized); not accessible for intervention)	3.5 Unacceptable. Replacement necessary	4.5 Form is com-pletely unsatis-factory and/or lost. Repair not feasible/reasonable, replacement needed

Table 2: Functional properties (FDI Criteria)

B. Functional properties	5. Fractures and retention	6. Marginal adaptation	7. Wear	8. Contact point/ food impact
1. Clinically excellent/ very good	5.1 Provisonal retained, no fractures/cracks	6.1 Harmonious outline, no gaps, no discoloration	7.1 Physiological wear equivalent to enamel (80-120% of corresponding enamel)	8.1 Normal contact point (floss can be inserted)
2. Clinically good (after polishing very good)	5.2 Small hairline crack	6.2.1 Marginal gap (<150 µm) 6.2.2 Small marginal fracture removable by polishing	7.2 Normal wear with only slight difference to enamel (50-80% or 120-150% of corresponding enamel)	8.2. Slightly too strong but no disadvantage
3. Clinically sufficient / satisfactory (minor shortcomings, no unacceptable effects)	5.3 Two or more or larger hairline cracks and/or chipping (not affecting the marginal integrity or proximal contact)	6.3 Gap < 250 µm	7.3. Differing wear rate to enamel but within biological variation (< 50% or 150-300% of corresponding enamel)	8.3. Slightly too weak, no indication of damage to tooth, gingivae or periodontal structures
4. Clinically unsatisfactory (but reparable)	5.4 Chipping fractures which damage marginal quality or proximal contacts; bulk fractures with or without partial loss (less than half of the restoration)	6.4.1 Gap > 250 µm 6.4.2 Chip fracture damaging margins 6.4.3 Notable marginal fractures	7.4 Wear considerably exceeds normal enamel wear; or occlusal contact points are lost (restoration >300% of enamel wear or antagonist > 300%)	8.4 Too weak (food impaction)
5. Clinically poor (replacement necessary)	5.5 (Partial or complete) loss of restoration	6.5 ICD is loose or lost	7.5 Wear is excessive (restoration or antagonist > 500% of corresponding enamel)	8.5 Too weak and/ or clear damage (food impaction) and/or pain/ gingivitis. Requires replacement

Table 3: Biologic properties (FDI Criteria)

C. Biological properties	**9. Postoperative (hyper-)sensitivity and tooth vitality**	**10. Periodontal response (always compared to a reference tooth)**	**11. Adjacent mucosa**
1. Clinically very good	9.1 No hypersensitivity, normal vitality	10.1. No plaque, no inflammation, no pockets	11.1 Healthy mucosa adjacent to restoration
2. Clinically good (after correction very good)	9.2 Low hypersensitivity for a limited period of time, normal vitality	10.2. Little plaque, no inflammation (gingivitis), no pocket development	11.2 Healthy after minor removal of mechanical irritations (sharp edges etc.)
3.Clinically sufficient/ satisfactory (minor shortcomings with no adverse effects but not adjustable without damage to the tooth)	9.3.1 Premature/ slightly more intense 9.3.2 Delayed/ weak sensitivity; no subjective complaints, no treatment needed	10.3.1 Plaque accumulation at acceptable level 10.3.2 Gingival bleeding acceptable 10.3.3 Pocket formation acceptable	11.3 Alteration of mucosa but no suspicion of causal relationship with filling material
4. Clinically unsatisfactory (repair for prophylactic reasons)	9.4.1 Premature/ very intense 9.4.2 Extremely delayed/weak with subjective complaints 9.4.3 Negative sensitivity. Intervention necessary but no replacement	10.4.1 Plaque accumulation not acceptable 10.4.2 Gingival bleeding not acceptable 10.4.3 Pocket depth increase > 1 mm compared to reference tooth	11.4 Suspected mild allergic, lichenoid or toxicological reaction
5. Clinically poor (replacement necessary)	9.5 Very intense, acute pulpitis or nonvital. Endodontic treatment is necessary and restoration has to be replaced	10.5 Severe/acute gingivitis or periodontitis	11.5 Suspected severe allergic, lichenoid or toxicological reaction

Table 4. Baseline FDI Score

	Integrity	Temp CB
1. Surface Luster	3	3
2. Surface Staining	1	1
3. Color Stability	1	2
4. Anatomic Form	2	1
5. Fractures & Retention	1	1
6. Marginal Adaptation	1	1
7. Wear	1	1
8. Contact point/Food impact	1	1
9. Post-op Sensitivity	1	1
10. Periodontal	1	1
11. Adjacent mucosa	1	1

Table 5. 3-Month FDI Score

	Integrity	Temp CB
1. Surface Luster	2	2
2. Surface Staining	2	1
3. Color Stability	2	1
4. Anatomic Form	3	2
5. Fractures & Retention	1	1
6. Marginal Adaptation	1	2
7. Wear	1	1
8. Contact point/Food impact	1	3
9. Post-op Sensitivity	1	1
10. Periodontal	2	2
11. Adjacent mucosa	1	1

Figure 1. Medit i700 scanner

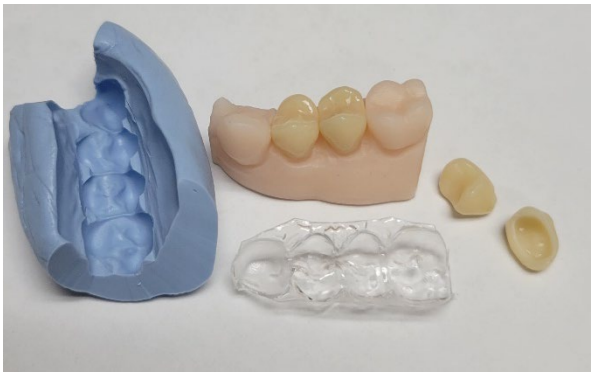

Figure 2. Printed crowns and provisional matrices

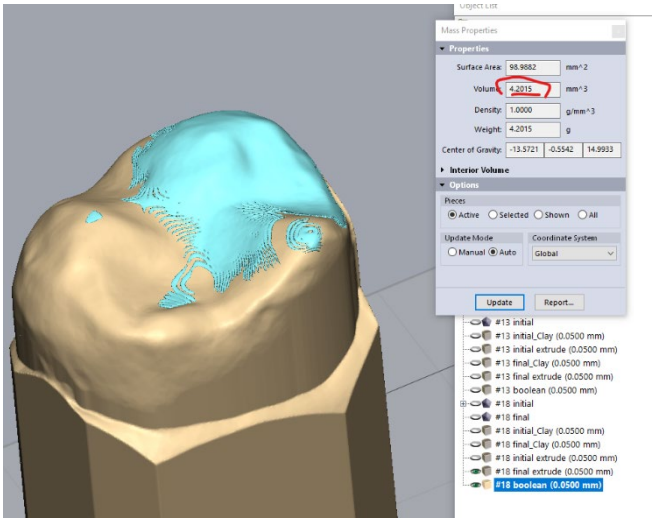

Figure 3. Volumetric wear Integrity® crown. Light blue color shows areas of wear at 3-months (tooth #18).

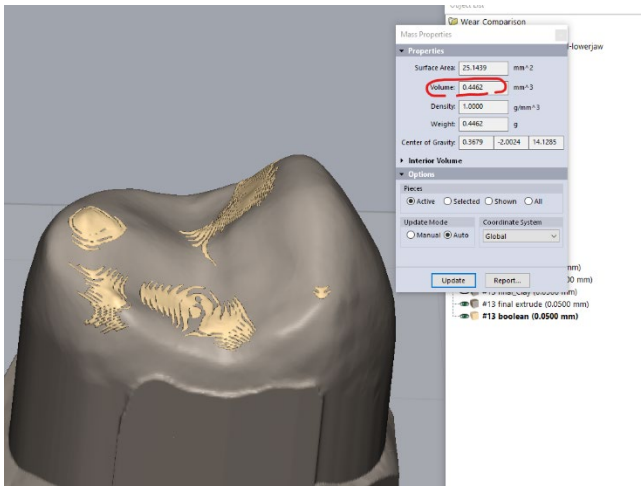

Figure 4. Volumetric wear Temporary CB printed crown. Light tan color shows areas of wear at 3-months (tooth #13)

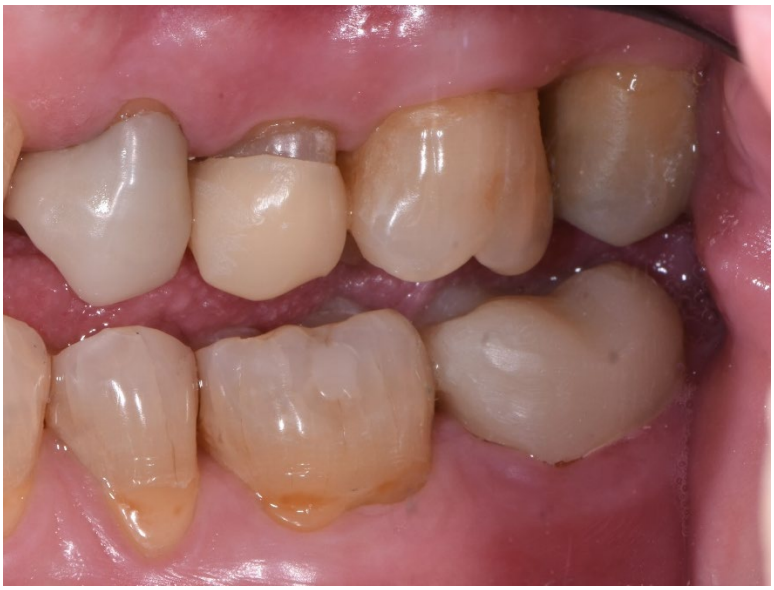

Figure 5. Baseline photo of tooth #13 (Temporary CB) and tooth #18 (Integrity®)

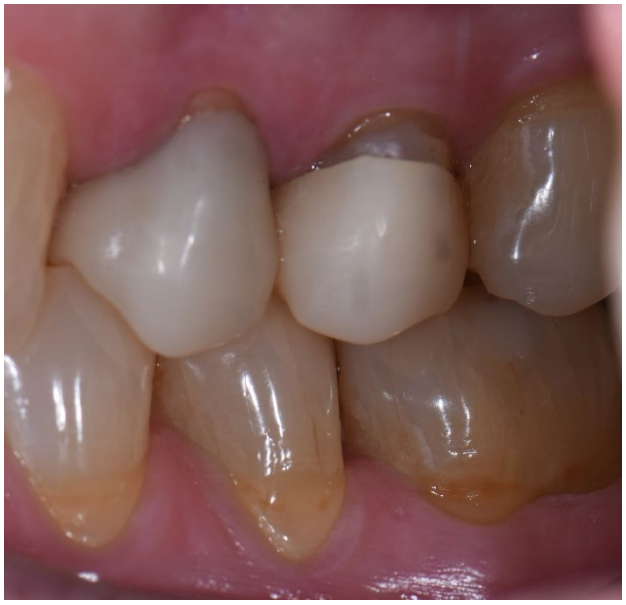

Figure 6. 3-month photo of tooth #13 (Temporary CB)

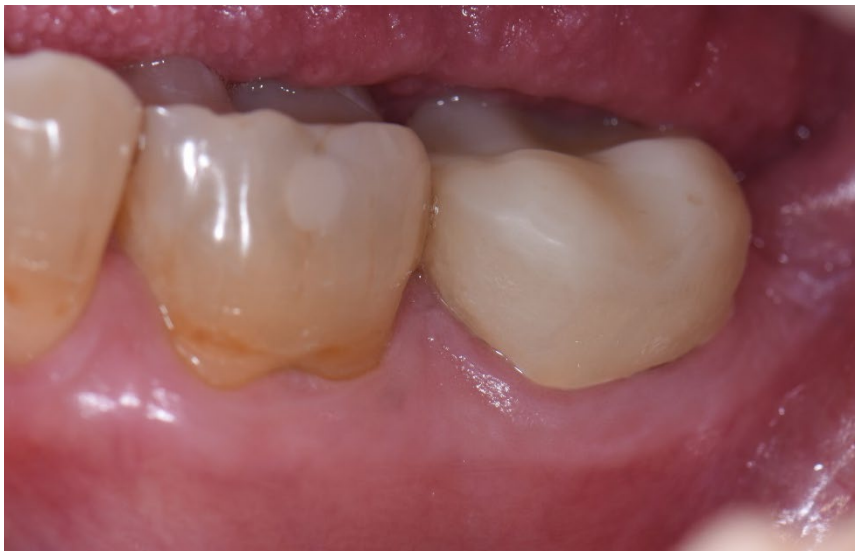

Figure 7. 3-month photo of tooth #18 (Integrity®)