Interim restorations are used to protect the pulp against thermal, mechanical, physical, and bacterial contamination.1,2 As traditional poly(methyl methacrylate)-based resin (PMMA) possesses low mechanical properties, attempts have been made to reinforce this material with fillers such as glass,3-8 silica,9 carbon fiber,6,8 steel wires,8,10 and polyaramid.3,11 Other disadvantages of PMMA interim restorations include their lack of marginal integrity12,13 and poor color stability because of a porous surface that attracts stains.14,15 Additionally, their high polymerization shrinkage, heat generation, water sorption, and degradation of the resin matrix are of concern.16 Interim restorations are commonly fabricated from templates of the required morphology, which are filled with the resin material and seated

**ABSTRACT**

**Statement of problem.** Interim restorations represent an essential treatment step; however, the optimal resin material for long-term interim restorations requires investigation.

**Purpose.** The purpose of this in vitro study was to compare the color stability, water sorption, wear resistance, surface hardness, fracture resistance, and microleakage of computer-aided design/computer-aided manufacturing (CAD/CAM) fabricated interim restorations with those of manually fabricated interim restorations.

**Material and methods.** Epoxy replicas were made from a prepared maxillary first premolar. On the replicas, interim crowns were fabricated and divided into the following groups: CAD/CAM poly(methyl methacrylate) (PMMA) blocks (CC), autopolymerizing temporary resin (AP), automix temporary resin (AM), and thermoplastic resin (TP). After cementation, all specimens were subjected to thermocycling and dynamic fatigue. The CIE Laboratory color coordinates were then recorded before and after immersion in coffee, tea, carbonated cola, and red wine. Water sorption was evaluated by using an immersion technique. Wear resistance was measured in a surface abrasion device. Vickers microhardness was measured on polished specimens. Fracture resistance was evaluated by axial loading with a universal testing machine. Marginal dye penetration was evaluated by sectioning the interim restorations after immersion in methylene blue (α=0.05).

**Results.** Colorimetric analysis revealed a large degree of color alteration (ΔE) in the manually fabricated interim restorations: AP = ΔE of 6.7 ±2; AM = ΔE of 7.1 ±1.5, and TP = ΔE of =5.4 ±3.1. The CC group demonstrated color stability (ΔE=2.1 ±0.2). CAD/CAM interim restorations demonstrated significantly lower water sorption, higher wear resistance, higher surface hardness, and significantly higher fracture resistance (1 289±56N) compared with manually fabricated interim restorations (AP=996 ±45, AM=899 ±37, and TP=1179 ±41). The stereomicroscopic examination of sectioned specimens demonstrated the absence of dye penetration in all tested specimens.

**Conclusions.** CAD/CAM interim crowns presented stable physical and mechanical properties and may be used for long-term interim restorations. (J Prosthet Dent 2015;114:414-419)
Clinical Implications

Results of the current study suggest that CAD/CAM-fabricated interim restorations may present stable, long-term clinical outcomes compared with those of conventional manually fabricated interim restorations.

over the prepared teeth.17,18 This technique requires laboratory and chairside time because adjustments may be necessary. However, improved interim restorative materials with better esthetics and longevity have been introduced.19 Bis-glycidyl methacrylate and bis-acryl-based materials are more color stable and have lower polymerization shrinkage and better mechanical properties than acrylic resins.20-23

Recently, thermoplastic materials have been introduced for the fabrication of interim restorations with the indirect technique. Because these materials require special equipment and are technique sensitive, the materials have been used with rapid prototyping, including both liquid-based stereolithography and powder-based 3-dimensional (3D) printing.24-26

Long-term interim restorations are necessary for oral implantation treatment or in situations involving comprehensive occlusal reconstruction, where the restorations could face extended functional loading.27 Thus, the interim material should possess optimum mechanical properties, color stability, and marginal integrity28 and may also serve as a guide for soft tissue healing.29 Numerous studies have addressed the issue of strengthening manually fabricated interim restorations.30,31 Computer-assisted design/computer-assisted machining (CAD/CAM) allows the milling of 3D-designed objects from bulk material, and the technique is reported to provide high precision.32 CAD/CAM interim restorations are made from preprocessed acrylic resin blocks and are reported to possess better color stability and more precise marginal quality than conventionally processed resin.33-35

The purpose of this study was to compare the color stability, water sorption, wear resistance, surface hardness, fracture resistance, and microleakage of CAD/CAM-fabricated interim crowns with those of conventionally fabricated interim crowns.

MATERIAL AND METHODS

A maxillary first premolar was prepared to receive a ceramic fixed restoration with a 1.5-mm occlusal reduction, 1-mm round finish line, and 6-degree convergence angle. The prepared tooth was embedded in an epoxy resin (Tri-Epoxy; Keystone Industries) base. A silicone impression (Hydorise; Zhermack) was made of the whole assembly and poured to fabricate epoxy resin (Tri-Epoxy) and stone dies (Elite Master; Zhermack SpA). Thereafter, 4 different interim crowns were generated by using the following procedures.

In the CAD/CAM PMMA (CC) group, dies were scanned (S 50 Zenotec CAD; Wieland Dental) to produce a CAD model for a complete maxillary premolar. Premolars were milled from a CAD/CAM PMMA block (Cercon base PMMA blocks; DeguDent GmbH). Three silicone indices were made of the produced CAD/CAM crown with polyvinyl siloxane (Hydorise putty; Zhermack). The indices were used as templates for the other groups.

In the autopolymerizing temporary resin (AP) group, cocoa butter was applied to the dies to prevent the interim material from adhering. Acrylic resin (Alike; GC Europe) powder and liquid were mixed according to the manufacturer’s instructions and loaded into the index and placed on the dies until completely set. The crowns were then removed, finished, and polished using rotary rubber cups (Komet Dental Gebr Brasseler GmbH).

In the automix temporary resin (AM) group, the 2-component automixing cartridge (Acrytemp; Zhermack) resin was loaded into a self-mixing gun and injected into the silicone index and placed on the corresponding die. After complete setting, the interim crowns were finished and polished as previously described.

In the thermoplastic resin (TP) group, a silicone index was cut into halves, and an access hole was drilled into each half. Crystalline acetal copolymer resin (Duracetal; Myerson LLC) was loaded into a special heating gun and injected into the 2 parts of the mold after being assembled on the preheated stone die. Material properties are summarized in Table 1.

Zinc oxide-based interim cement (RelyX Temp NE; 3M ESPE) was mixed on a waxed paper pad, and a plastic filling instrument was used to fill each interim restoration, which was seated in its corresponding epoxy die under a fixed load of approximately 5.0 N. Excess cement was removed with a cotton pellet after 30 minutes. The cemented specimens were stored under distilled water at room temperature for 48 hours before testing.

The 3 coordinates of color (CIELab) were measured with a calibrated dental colorimeter (Easyshade Advance; Vita Zahnfabrik) immediately after cementation of the

Table 1. Material composition

<table>
<thead>
<tr>
<th>Material Composition</th>
<th>Manufacturer</th>
</tr>
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<tbody>
<tr>
<td>Cercon base PMMA blocks</td>
<td>DeguDent GmbH</td>
</tr>
<tr>
<td>Alike MMA/PMMA</td>
<td>Zhermack</td>
</tr>
<tr>
<td>Acrytemp Bis-acrylic autopolymerizing compound</td>
<td>Zhermack</td>
</tr>
<tr>
<td>DurAcetal Highly crystalline acetal copolymer resin</td>
<td>Myerson LLC</td>
</tr>
</tbody>
</table>

CAD/CAM, computer-aided design/computer-aided manufacture; MMA, methacrylate monomer; PMMA, polymethyl methacrylate. 415
interim restorations. A dark box was used to prevent external light reflection. Each cemented specimen was stored for 1 week in 1 of the following solutions: coffee (Nescafe Gold; Nestle), tea (Lipton Yellow Label; Unilever), carbonated cola (Pepsi; PepsiCo), and red wine. The solutions were replaced every 6 hours, and the surface of each restoration was manually brushed with toothpaste. Color parameters were measured again after 6 weeks, and the change in color was evaluated from the following equation:

$$\Delta E = \sqrt{(L_2-L_1)^2+(a_2-a_1)^2+(b_2-b_1)^2},$$

where Lab1 is the color coordinate after cementation and Lab2 values are the color coordinates after immersion in the staining solutions. $\Delta E$ of $>4.2$ was considered unacceptable color change as observed by the naked eye.36

Uncemented specimens were immersed in distilled water for 3 months at a temperature of 37°C. Specimens were weighed on a digital balance (PXC 200 series; Intelligent Weighing Technology, Inc). The increase in weight from new to immersed specimens was used as the water sorption ratio.37

Cemented specimens were highly polished with a bristle brush and 0.05-μm diamond paste. The polished specimens were placed in a mastication simulator (CS 4.8, SD Mechatronics) device, and a paste of rice shells was added as the abrasive material. The specimens were subjected to 2 million cycles at a load of 40 N and were then ultrasonically cleaned, dried, and gold sputter coated before scanning electron microscopy imaging (XL 30; Philips). Each specimen was digitally photographed (D7000; Nikon Corp) before and after mastication simulation, and the images were superimposed to detect areas of material loss. The percentage of weight loss was used to indicate material loss from friction and wear.

Highly polished disks (10×3 mm) were fabricated from a mold for all manually fabricated groups and milled for the CAD/CAM group. All disks were subjected to the Vickers microindentation test under a load of 4.9 N for 30 seconds contact time. Indentation diagonals were used to calculate surface hardness.38

A plastic mold (18×3×2 mm) was used to prepare bar-shaped specimens of the manual interim materials, whereas the CAD/CAM milling block was sectioned with a precision cutting machine (IsoMet 5000 Linear precision saw; IsoMet Corp) to obtain bars of the previous dimensions. Specimens were loaded in a 4-point bending test (18- and 10-mm roller supports) until fracture with a universal testing machine (Accuforce Elite test stand: Ametek) loaded at a crosshead speed of 1 mm/minute until failure occurred. The load deformation curve was used to accurately mark the fracture point.40

Cemented interim restorations were thermocycled (50 000 cycles, 5 to 60°C, and dwell time of 3 minutes) and immersed in methylene blue dye for 24 hours. Specimens were sectioned with a precision cutting machine (IsoMet 5000 linear precision saw; IsoMet Corp), and cut sections were examined under an optical microscope (SZ 11; Olympus Corp) at ×30 magnification to evaluate the extent of dye penetration. Dye penetration was traced along the cement film thickness in micrometers.

Data were analyzed with 1-way analysis of variance (ANOVA) and the Bonferroni post hoc test ($\alpha=.05$) with statistical software (SPSS v10; SPSS Inc). According to sample size ($n=20$ per test), medium effect size, the test of choice had adequate power to detect clinically relevant differences. To determine the homogeneity of variance, F-tests were used. Where an assumption of homogeneity of variance for statistical analysis was violated, multiple F-tests were used with adjusted table values where indicated to confirm the ANOVA results.31 The alpha level for statistical significance was fixed at .05.

**RESULTS**

Colorimetric analysis of data revealed unacceptable color change of ($\Delta E > 7.7$) in manually fabricated specimens, whereas CAD/CAM specimens maintained their original color ($\Delta E < 2.4$). All manually fabricated specimens were associated with a significant decrease in the L value (restorations having darker color) and a significant increase in the yellow scale ($b^*$). Moreover, these restorations were occasionally associated with observable surface scratches and air bubbles, which attracted further staining.

Manually fabricated interim restorations were associated with significantly higher ($F=32, P<.02$) water
sorption than acetal-based and CAD/CAM interim restorations. Image superimposition of specimens indicated volumetric material loss at the cusp tips and slopes of all used materials (Fig. 1). Scanning electron microscopy (SEM) images of specimens placed in an accelerated wear device revealed deterioration of the resin matrix in all specimens, which was observed to a lesser extent in CAD/CAM-fabricated specimens (Fig. 2). CAD/CAM interim restorations were also associated with significantly higher fracture resistance ($F=14$, $P<.02$) and surface hardness than manually fabricated interim restorations (Table 2). Stereomicroscopy examination of the sectioned specimens demonstrated no dye penetration in any of the tested specimens and no discoloration of the interim cement (Fig. 3).

**DISCUSSION**

This study investigated and compared material properties of CAD/CAM-fabricated interim crowns with those of conventional, manually fabricated interim crowns. Results of the study indicated that CAD/CAM-fabricated crowns presented better color stability, higher mechanical properties, and better fit than the other groups tested.

The composition of the resin matrix and its polymerization methods may have great effect on its color stability as discoloration of light-polymerized materials begins soon after its exposure to the oral cavity. Although there may be differences in the progression rate depending on their composition, polymerized resin materials gradually deteriorate. Moreover, as expected, higher water sorption values were recorded for the manually fabricated interim specimens, which is most likely related to the polymerization method, higher residual monomer ratio, and higher porosity.

Published reports show that inferior surface hardness, flexure strength, and fracture resistance are reported for acetal-based interim restorations compared with CAD/CAM-fabricated interim restorations. However, evidence is lacking with regard to the stability of acetal-based material under the influence of water, and this would be a consideration for future investigations. However, all specimens from the acetal-based group exceeded 600 N, which is the threshold for withstanding occlusal load in the posterior region.

CAD/CAM PMMA blocks are industrially polymerized under optimum manufacturing conditions. Such conditions offer those interim restoration better mechanical properties than those that are manually fabricated. Their good mechanical properties represent a solution for long-term interim restorations where strength and color stability are required. Moreover, the improved fit of the milled CAD/CAM products should lower the risk of bacterial contamination of the tooth and prevent damage to the pulp from excessive temperature changes.

An interesting finding was the absence of dye penetration of all tested specimens after 50,000 cycles of thermocycling. The interim cement used and the accuracy of marginal fit (Fig. 3) may well have resulted in an excellent marginal seal and resisted dye penetration. This is in contrast to other reports in which microleakage from interim restorations was commonly observed after the use of interim cements. This is an indication that the

**Table 2.** Physical and mechanical properties of different test groups

<table>
<thead>
<tr>
<th>Material</th>
<th>$\Delta E$</th>
<th>Water Sorption (mm/mm$^3$)</th>
<th>Wear (wt%)</th>
<th>Micro-Hardness (VHN)</th>
<th>Flexure Strength (MPa)</th>
<th>Fracture Resistance (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAD/CAM Cercon</td>
<td>2.1 ±0.2</td>
<td>8.7 ±0.7</td>
<td>0.0012</td>
<td>21.2 ±1</td>
<td>142 ±12</td>
<td>1 289 ±56</td>
</tr>
<tr>
<td>Alike</td>
<td>6.7 ±2</td>
<td>28.5 ±2</td>
<td>0.0021</td>
<td>16.3 ±2.1</td>
<td>111 ±9</td>
<td>996 ±45</td>
</tr>
<tr>
<td>Acrytemp</td>
<td>7.1 ±1.5</td>
<td>19.6 ±3</td>
<td>0.0015</td>
<td>18.5 ±1</td>
<td>118 ±8</td>
<td>899 ±37</td>
</tr>
<tr>
<td>DurAcetal</td>
<td>5.4 ±3.1</td>
<td>7.4 ±1.3</td>
<td>0.0011</td>
<td>19.2 ±2</td>
<td>126 ±2.5</td>
<td>1 179 ±41</td>
</tr>
</tbody>
</table>

CAD/CAM, computer-aided design/computer-aided manufacture; $\Delta E$, color difference; VHN, Vickers hardness number.
quality of the conventional interim restoration is technique and experience sensitive and could depend on these factors. From this perspective, the CAD/CAM fabricated interim crown may be beneficial because of its reproducibility and accuracy.

CONCLUSIONS

Within the limitations of the present in vitro study, CAD/CAM interim crowns showed improved color stability and physical and mechanical properties compared to conventionally fabricated crowns. CAD/CAM fabrication is applicable for long-term clinical interim restorations.

REFERENCES


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