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Differences in Radiopacity, Surface Properties, and Plaque Accumulation for CAD/CAM-Fabricated vs Conventionally Processed Polymer-based Temporary Materials

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Clinical Relevance

As temporary materials are often used in prosthetic dentistry, there is need to investigate their behavior in the oral environment. Parameters such as surface roughness and surface free energy correlate to the level of plaque adhesion, which can impact gingival health.

SUMMARY

Objective: To test computer-aided design/computer-aided manufacturing (CAD/CAM)-fabricated and conventionally processed polymer-based temporary materials in terms of radiopacity (RO), surface free energy (SFE), surface roughness (SR), and plaque accumulation (PA).

Methods and Materials: Six temporary materials (n=10/n=10) were tested, including three CAD/CAM-fabricated (CC) materials—Art Bloc Temp (CC-ABT), Telio CAD (CC-TC), and VITA CAD Temp (CC-VCT)—and three conventionally processed (cp) materials: Integrity Multi Cure (cp-IMC), Luxatemp Automix Plus (cp-LAP), and Protemp 4 (cp-PT4). Zirconia acted as the control group (CG, n=10). RO was evaluated according to DIN EN ISO 13116. SFE was investigated using contact angle measurements. SR was measured using a profilometer. The PA tests were performed using three microorganisms: *Streptococcus mutans*, *Actinomyces naeslundii*, and *Veillonella parvu-*

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***la*. Data were analyzed using Kolmogorov-Smirnov, Kruskal-Wallis, Mann-Whitney *U*-, Dunn-Bonferroni, Wilcoxon, Levene, and Pearson tests and one-way analysis of variance with post hoc Scheffé test (α=0.05).**

Results: No radiopacity was observed for any CC material or cp-PT4. CG showed the highest RO, while no differences between cp-IMC and cp-LAP were found. CG showed lower SFE compared to all polymer temporary materials, except in the case of CC-TC. cp-LAP and cp-IMC presented higher SFE than did CC-TC and CG. CC-ABT presented lower initial SR values compared to cp-PT4 and cp-LAP. For cp-LAP, a higher initial SR was measured than for all CAD/CAM materials and cp-IMC. All specimens showed a certain amount of PA after the incubation period. *A naeslundii* and *V parvula* resulted in comparable PA values, whereas the values for *S mutans* were lower by one log level. CAD/CAM materials showed superior results for SR, SFE, and PA, whereas all materials lacked RO.

INTRODUCTION

Prosthetic treatments for fixed dental prostheses (FDPs) such as veneers, crowns, and fixed partial dentures generally depend on indirect fabrication of the definite restoration in the laboratory. Over the period of the laboratory production, which usually takes about seven to 12 days, provisional restoration is necessary to protect the prepared tooth. The fabrication of provisional restorations protects the prepared tooth surfaces from thermal, mechanical, and biological noxae and provides functional, phonetic, diagnostic, esthetic, and stabilizing value.[1–5] There are a great variety of materials and techniques for provisional restorations.[6] Common dental materials used in restorative techniques are tooth-colored polyethylmethacrylates (PEMA) and polymethylmethacrylates (PMMAs), bisphenol A-glycidyl methacrylates (Bis-GMAs), and glass-fiber reinforced composites. Provisional restorations can be produced directly on the prepared tooth or indirectly in the conventional way in the laboratory. These are in contrast to the computer-aided design/computer-aided manufacturing (CAD/CAM) techniques using advanced materials, which enable the fabrication of both provisional and definitive restorations with higher mechanical strength and better clinical outcomes.[7] Provisional restorations may provide short-term function until the definitive restoration has been fabricated or long-term function during a longer course of treatment, such as one involving complete-mouth prosthodontic treatments, oral surgery, or orthodontic or endodontic procedures.[8] The quality of the provisional restoration highly affects the success of treatment outcomes; thus, materials with good mechanical properties as well as dimensional stability and color stability are required. Regarding surface roughness, values of 0.22-1.5 μm are reported for temporary materials.[9–11] In addition, most dental provisional composites are radiolucent and are not visible with standard radiographic techniques, so they challenge good control and easy detection of surplus temporary materials, in contrast to opaque materials such as zirconia. To date, there are very few studies in the literature describing radiopacity of temporary materials; a single study[12] reports no radiopacity (RO) for Telio CAD. In terms of fabrication, a precise marginal fit allows one to maintain gingival health by preventing plaque accumulation around poorly fit margins, which would lead to irritation or inflammation of the periodontal tissues.[1,5,13] Dental plaque, a complex biofilm, is produced by colonization of over 500 bacterial species following a regimented pattern; initial colonizers adhere to the enamel salivary pellicle followed by secondary colonizers showing interbacterial adhesion.[14,15] Plaque development contributes to diseases such as caries, gingivitis, and periodontal disease.[15] Most bacteria in the oral cavity can only survive if they stick to the hard surfaces of teeth, filling materials, prostheses, or dental implants.[16] These different hard surfaces with different chemical characteristics as well as different surface characteristics (such as surface roughness [SR] and surface free energy [SFE] values) can retain varying quantities of bacterial plaque. SR and SFE have a major impact on the initial adhesion and the retention of oral microorganisms.[17] The smaller the SFE or the SR, the lower the plaque accumulation, thereby reducing the risk for periodontal infections.[16] FDPs should generally have highly polished surfaces in order to reduce plaque accumulation (PA) and gingival damage, leading to conditions free from inflammation.[16,18–21] This inflammation could lead to bleeding from the gingiva during the try-in process of the restoration, which affects the quality of adhesive restorative techniques.[16]

In summary, the main goal of all provisional materials should be the fabrication of high-quality and well-fitting temporary restorations with smooth surfaces, enhancing patient health during treatment periods.

Table 1: *Summary of Tested Materials Including Polymer-based Temporary Materials and Control Group Categorized by Type of Material, Product Name, Abbreviation, Manufacturer, Lot No., and Chemical Composition*

Type of Material	Product Name, Shade	Abbreviation	Manufacturer	Lot No.	Chemical Composition, wt%
Polymer-based temporary materials					
Conventionally processed	Integrity Multi Cure, A2 (dual-curing)	cp-IMC	Dentsply Sirona, York, PA, USA	170511	Urethane-modified Bis-GMA, DMA
	Luxatemp Automix Plus, A3.5 (self-curing)	cp-LAP	DMG, Hamburg, Germany	772091	PMMA, SiO_2, UDMA, DMA, Bis-GMA
	Protemp 4, A2 (self-curing)	cp-PT4	3M, Seefeld, Germany	6600623	PUR 10%-20%, silanized SiO_2 5%-10%, DMA 50%-60%, amorphous SiO_2 20%-30%
CAD/CAM fabricated	Art BlocTemp, BL2	CC-ABT	Merz Dental, Lütjenburg, Germany	52808	PMMA, MMA <1%, dibenzoyl peroxide 0%
	VITA CAD Temp, 1M2T/CT40	CC-VCT	VITA Zahnfabrik, Bad Säckingen, Germany	11000	PMMA, SiO_2 14%, pigments
	Telio CAD, LT A2	CC-TC	Ivoclar Vivadent, Schaan, Liechtenstein	R36500	PMMA 99.5%, pigments <1.0%
Zirconia (control group)	Nexx Zr Zirkonoxid	CG	Sagemax Bioceramics, Federal Way, WA, USA	GEMBD	$ZrO_2 \geq 89\%$, Y_2O_3 4%-6%, $HfO_2 \leq 5\%$, Al_2O_3 <1%

Abbreviations: Al_2O_3, alumina; DMA, dimethacrylate; HfO_2, hafnium dioxide; PUR, polyurethane; SiO_2, silicium dioxide; UDMA, urethane dimethacrylate; Y_2O_3, yttria; ZrO_2, zirconia.

The null hypothesis of this investigation was that no differences in RO, SFE, SR, and PA exist between three CAD/CAM-fabricated (CC) and three conventionally processed (cp) polymer-based temporary materials.

METHODS AND MATERIALS

The RO, SFE, SR, and PA of six polymer-based temporary materials (three CC and three cp materials [Table 1]), were determined and compared with zirconia (Nexx Zr Zirkonoxid, Sagemax Bioceramics, Federal Way, WA, USA), which served as a control group (CG) (Figure 1).

Specimen Preparation

Thirty disc-shaped specimens with a diameter of 10 mm and a thickness of 2 mm were milled (Cerec MCXL, Dentsply Sirona Inc, York, PA, USA) from three polymer-based CC temporary materials (n=10/CC material), namely Art Bloc Temp BL2 (CC-ABT, Merz Dental, Lütjenburg, Germany), Telio CAD LT A2 (CC-TC, Ivoclar Vivadent, Schaan, Liechtenstein), and VITA CAD Temp IM2T/CT40 (CC-VCT, VITA Zahnfabrik, Bad Säckingen, Germany). For the CG, 10 specimens were milled to be "overdimensioned" from zirconia and sintered according to manufacturer's instructions.

Using the CC specimens, standardized silicone molds with a diameter of 10 mm and a thickness of 2 mm were created as templates to produce 30 cp specimens. For this, the polymer-based cp temporary materials (n=10/cp material), namely Integrity Multi Cure A2 (cp-IMC, Dentsply Sirona), Luxatemp Automix Plus A3.5 (cp-LAP, DMG, Hamburg, Germany), and Protemp 4 A2 (cp-PT4, 3M, Seefeld, Germany), were filled into the silicone molds and allowed to polymerize for 10 minutes. The dual-curing cp-IMC was additionally light-cured (20 seconds) (Elipar S10, 3M).

All specimens were polished with a laboratory polishing machine (Abramin, Struers, Ballerup, Denmark) and silicon carbide paper up to P2000 (SiC Foil, Struers) under permanent water-cooling to a final thickness of 1 ± 0.03 mm. For all polymer-based temporary materials, preliminary polishing was performed with a goat-hair brush (diameter of 20 mm, Polirapid, Singen, Germany) and polishing paste (Signum HP Paste, Kulzer, Hanau, Germany); this step was followed by ultrasonic cleaning in distilled water (Ultrasonic T-14, L&R Manufacturing Co, Keamy, NJ, USA) and high-gloss polishing with a linen buffing wheel (Komet Dental, Lemgo, Germany). For zirconia specimens, preliminary and high-gloss polishing was performed using a polisher containing diamond grit particles and a felt wheel with polishing paste (Dia Glace, Yeti Dental, Engen, Germany), respectively. All manual polishing steps were performed according to standardized polishing protocols using a hand piece at a maximum speed of 6000 rpm. After polishing, all specimens were stored

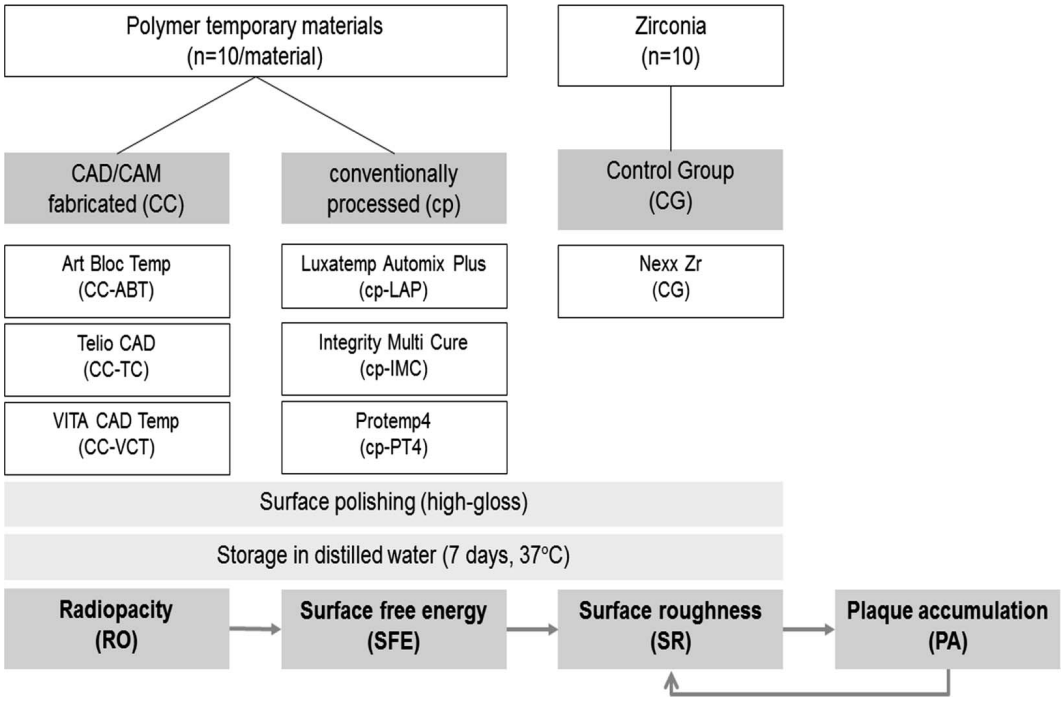

Figure 1. *Study design for testing differences in radiopacity, surface properties, and plaque accumulation for CAD/CAM-fabricated vs conventionally processed polymer-based temporary materials.*

in distilled water for seven days at 37°C (HeraCell 150i, Kulzer).

Analysis of RO

The RO was evaluated according to DIN EN ISO 13116.[17] The specimens of each material were arranged on radiographic films (Insight IP-21, Carestream Dental, Stuttgart, Germany) with an aluminum step wedge with variable thickness (from 0.3 mm to 6.3 mm in 0.3-mm increments). Conventional x-rays were taken by an intraoral x-ray unit (Heliodent DS, Dentsply Sirona) operating at 60 kV, 7 mA, and 0.16 seconds by maintaining the same positioning of the x-ray unit throughout the analysis of RO of all materials. Each group was radiographed three times before the position on the aluminum wedge was adjusted. Three different positions (bottom, middle, and top) on the same aluminum step wedge were examined to obtain a varying reference for the RO of each material. Radiographic films were developed with standard developing solution according to manufacturer's instructions. Images were transferred to a computer and loaded into a picture-editing software (Adobe Photoshop PS4, Adobe Systems, San Jose, CA, USA) for evaluation. After creating a standard curve based on the gray values of the aluminum step wedge, the RO of the specimens was calculated with the measurements report of the picture-editing software corresponding to the respective thickness of aluminum (mm/Al).

SFE Measurements

The SFE was investigated after ultrasonic cleaning in distilled water (Ultrasonic T-14, L&R Manufacturing) by measuring the contact angle (Kruess Easy Pearl, Kruess, Hamburg, Germany) of distilled water as polar and diiodomethane as dispersed test liquid at room temperature for each material (n=10/material). Successively, three drops, with a defined drop volume of each test liquid (6 μL of distilled water, 3 μL of diiodomethane), were positioned on different areas of the specimen surface. For each sessile drop, a picture was taken after five seconds. The baseline was adopted, the drop contour labeled, and the contact angles calculated using DSA 4 software (Drop Shape Analysis, Release 1.0, Kruess). For water the calculation method "Tangent 1" and for diiodomethane the calculation method "Circle" were applied. Finally, SFE was calculated according to the method of Owens-Wendt-Rabel-Kaelble.[18]

SR Measurements

The SR was measured (Mahr Perthometer SD 26, Mahr, Göttingen, Germany) twice, initially and after analysis of plaque accumulation, for each material (n=10/material). For both measurements, six read-

ings, including three horizontal and three vertical lines with a track length of 5.6 mm, were recorded with a distance of 0.25 mm in between. For each specimen, the mean value of the six readings was calculated and assigned as the SR value to the specimen.

Analysis of PA

For analyzing the PA, the specimens (n=10/material) were placed in 48-well plates (Greiner Bio-One, Kremsmünster, Austria) in an upright position and covered with 1.2 mL of brain-heart infusion medium (BD Diagnostics, Heidelberg, Germany). The experiments were performed using three microorganisms, namely *Streptococcus mutans* (*S mutans*, ATCC 25175, DSMZ, Heidelberg, Germany) and *Actinomyces naeslundii* (*A naeslundii*, ATCC 19039, DSMZ) as representatives for caries pathogens as well as *Veillonella parvula* (*V parvula*, ATCC 17745, DSMZ) as an early member of the periodontopathogenic biofilms close to the gingival margin. The strains were grown on Schaedler agar plates (BD Diagnostics) containing vitamin K1 and 5% sheep blood for 48 hours under defined culture conditions (37°C, 5.8% CO_2 for *S mutans* and *A naeslundii*; anaerobic chamber containing 5% H_2, 10% CO_2, 85% N_2 for *V parvula*). Each well, containing one specimen disc, was inoculated with 100 μL of the respective bacterial suspension (*S mutans, A naeslundii,* or *V parvula*) at an optical density of 0.5 measured at 600 nm in 0.9% sodium chloride (NaCl) solution (Varioskan Multiplate Reader, Thermo Fisher Scientific, Waltham, MA, USA). To allow the formation of adult biofilms, the plates were incubated for five days under the same culture conditions as described above. After incubation, the specimens were aseptically removed from the well plate, rinsed twice with 0.9% NaCl, and transferred to 15-mL Falcon tubes (Greiner Bio-One). The tubes were vortexed for 60 seconds to disrupt the biofilm. To determine the number of viable bacteria, a luminescence-based assay was performed (BacTiter-Glo, Promega, Mannheim, Germany). This assay measures the amount of adenosine triphosphate (ATP) present in the respective specimen, which is directly proportional to the number of viable bacterial cells. To each well of a 96-well plate 100 μL of the assay reagent was added and mixed with 10 μL of the bacterial sample. After an incubation time of five minutes, the luminescence was recorded by a luminescence reader (GloMax Navigator System, Promega). The measurement was performed in duplicate for each specimen (n=10/material).

Statistical Analysis

The assumption of normal distribution was tested using the Kolmogorov-Smirnov test. To investigate possible differences between the variances, the Levene test was performed. To determine differences between the tested materials nonparametric analyses, such as Kruskal-Wallis and Mann-Whitney *U*- and Wilcoxon tests were calculated for SFE, SR, and PA values. RO was analyzed using one-way analysis of variance with post hoc Scheffé test. Correlations were tested using the Pearson test. All *p*-values below 0.05 were construed as statistically significant. All statistical tests were performed using SPSS V5 statistics software (IBM, Armonk, NY, USA).

RESULTS

No radiopacity was detected for any CC polymer temporary material (CC-ABT, CC-VCT, CC-TC) or cp-PT4, as no x-ray shadow could be observed in the area of the specimens on the x-ray films. RO was only observed for cp-IMC, cp-LAP, and CG (Figure 2; Table 2). CG showed the highest values of RO ($p<0.001$), while no differences between cp-IMC and cp-LAP were found ($p>0.05$).

The CG showed lower SFE values compared to all polymer temporary materials, except CC-TC ($p<0.001$). Conventionally processed cp-LAP and cp-IMC presented higher SFE than did CC-TC and CG ($p<0.001$). The remaining materials showed no differences ($p>0.05$).

CC-ABT presented lower initial SR values compared to cp-PT4 and cp-LAP ($p<0.001$). For cp-LAP, a higher initial SR was measured than for all CC polymer temporary materials (CC-VCT, CC-TC, and CC-ABT) and the conventionally processed cp-IMC ($p<0.001$). After analysis of PA and cleaning, CC-TC showed lower SR compared with conventionally processed cp-PT4 and pc-LAP ($p<0.001$). Furthermore, an increase of SR values was observed for cp-PT4, CC-ABT and CC-VCT, and CG (Table 2).

Regarding PA, all specimens showed a certain amount of bacterial colonization after the incubation period. *A naeslundii* and *V parvula* resulted in comparable bacterial number values, whereas the values for *S mutans* were lower by one log level (Figure 3). Within all groups, homogeneous distribution of the variances for all bacterial species tested was found. Within the *S mutans* and *A naeslundii* groups, no significant differences for the number of viable bacteria could be found between the materials tested. Within *V parvula*, significant differences

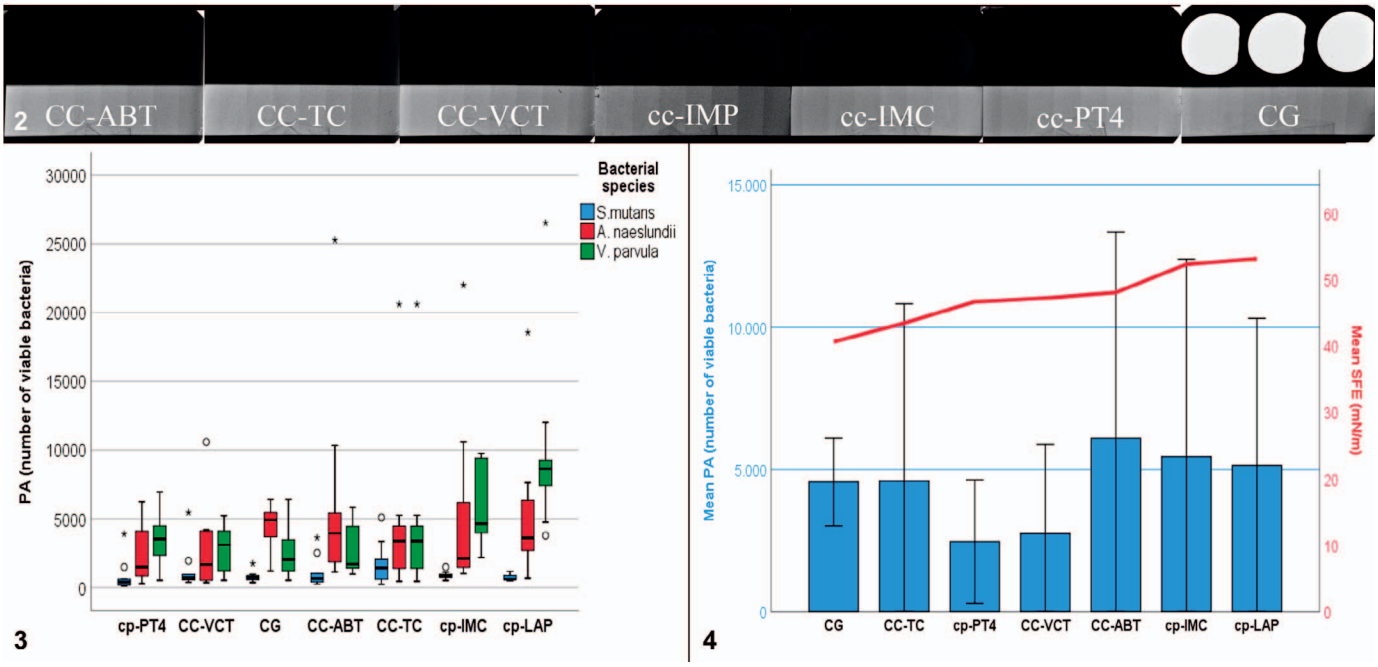

Figure 2. *Radiopacity (RO) of all tested materials.*

Figure 3. *PA (number of viable bacteria) according to the material and the bacterial species tested.*

Figure 4. *Correlation between PA (pooled data) and SFE values.*

were found ($p<0.001$), with higher bacterial colonization for cp-LAP compared to CG ($p=0.005$), and all CC temporary materials, namely CC-ABT ($p=0.009$), CC-VCT ($p=0.016$), and CC-TC ($p=0.033$).

A positive correlation was found between SFE values and pooled data of PA ($R=0.253$, $p=0.039$) (Figure 4).

DISCUSSION

This study aimed to evaluate different properties of polymer-based temporary restorative materials. Zirconia was chosen as a control because it is known for its excellent biocompatibility, surface properties, and high RO.[12,24] Regarding RO, the null hypothesis could be confirmed, as no temporary material showed any RO. The reason for this may be found in the composition of the materials, as they contain no components with high RO, such as zirconia or barium sulfate. These additives are used in other resins to improve their RO and could also be added to temporary materials. Although it is not necessary for temporary restorative materials to show similar RO values, a certain visibility in radiographs would be of interest to detect any excess restorative material. However, temporary materials not showing any RO do not have to be removed prior to presurgical cone beam computed tomography imaging, allowing practitioners to avoid interfering artifacts.

With regard to the SFE values, two cp materials (Luxatemp Automix Plus and Integrity Multi Cure) showed higher values than did the CC Telio CAD. Therefore, the stated hypothesis must be rejected. It seems that CAD/CAM processed materials generally show lower SFE values. This could be traced back to the industrial manufacturing process, particularly the polymerization process, realizing higher conversion rates and thus resulting in reduced quantities of functional groups on the polymer surface. The standardized manufacturing process could also be the reason for the obtained SR results, for which the cp materials also showed higher values compared to the CAD/CAM processed materials. In part, these results are confirmed by similar studies investigating different processed materials. Other groups reported tendential higher values.[9–11,25] This may be due to different polishing protocols, such as those involving different silicon polishers that are used chairside by the dentist. We chose a goat-hair brush with polishing paste, which is commonly used in dental laboratories.

During the microbiologic experiments, the specimens were cleaned mechanically by brushing, followed by 10 minutes of cleaning in an ultrasonic

Table 2: *Means and Standard Deviations for Surface Free Energy (SFE), Surface Roughness (SR), and Radiopacity (RO)*[a]

Type of Material	Product	SFE, mN/m	SR, μm			RO, mm/Al
			Initially	After Plaque Accumulation	*p*-Value Between SR Values	
Polymer-based temporary materials						
Conventionally processed	cp-IMC	52.4 ± 4.4 CD	0.054 ± 0.016 AB	0.074 ± 0.022 AB	0.051	8.01 ± 0.55 B
	cp-LAP	53.2 ± 3.3 D	0.099 ± 0.050* C	0.108 ± 0.017 B	0.139	8.45 ± 0.07 B
	cp-PT4	46.7 ± 1.4 BC	0.077 ± 0.012 BC	0.106 ± 0.033 B	0.011	0 A
CAD/CAM fabricated	CC-ABT	48.1 ± 5.0* BCD	0.041 ± 0.002 A	0.082 ± 0.006 AB	0.005	0 A
	CC-VCT	47.3 ± 4.1 BC	0.063 ± 0.014 AB	0.093 ± 0.020 AB	0.005	0 A
	CC-TC	43.2 ± 2.2 AB	0.051 ± 0.012 AB	0.071 ± 0.016 A	0.050	0 A
Zirconia (control group)	CG	40.7 ± 3.8 A	0.071 ± 0.009 ABC	0.090 ± 0.019* AB	0.009	226.7 ± 0.1 C

[a] *Different letters indicate significant differences among the tested materials.*
* *Indicates non–normally distributed groups.*

bath. This protocol may explain the increase in the SR values of all groups after microbiological testing. The applied cleaning process is similar to that used in the clinical situation, in which patients brush their teeth without paying particular attention to the temporary restorations. Thus, it is to be suspected that the surface properties of polymer-based temporary materials are changed after PA followed by a thorough cleaning. Another explanation for the observed differences in SR after testing the PA would be the alteration of the restoration surfaces by the bacterial colonization itself, which would lead to a "vicious cycle," compromising the quality of the surface over a longer time period.[26]

The SFE and the SR results influence the microbiological outcome. This is clearly demonstrated by the correlation between the SFE and the PA showing higher numbers of viable bacteria with increasing values of SFE. Higher bacterial counts of *Veillonella parvula* were found for the cp Luxatemp Automix Plus compared to all CC materials. Therefore, our hypothesis regarding PA must be rejected. *Veillonella parvula* plays an important role in the early stage of biofilm formation near the gingiva and opens the door for other periodontal pathogens, such as *Porphyromonas gingivalis* or *Fusobacterium nucleatum*.[27] A luminescence-based assay was used for the determination of the bacterial amount on the material surfaces. This assay measures the amount of ATP present in the tested cells, which is an indicator of the number of viable cells. Most previously published investigations use different kinds of staining or optical counting of cells.[28] Furthermore, a lot of different biofilm models are described in the literature.[29–31] This complicates the comparison of the present results to those of previous investigations. Other approaches in the literature tested temporary materials, with antimicrobial effects demonstrating promising results.[32]

For short-term restorative materials it is essential that no inflammation of the gingiva occurs during the temporary phase to avoid any bleeding during the restorative process. Regarding long-term temporary restorations, for which mainly CAD/CAM processed materials are used, this aspect must be widened for caries pathogens such as *Streptococcus mutans* and *Actinomyces naeslundii* because of the possibility of the formation of secondary caries on the restoration margin. Regarding *Streptococcus mutans* and *Actinomyces naeslundii*, no significant differences between the groups were found, which could be explained by the different adhesion mechanisms of these strains. Other reasons for differing PA rates are the chemical composition of the materials as well as further surface properties, such as SFE, SR, hydrophobicity, and surface-coating techniques.[33] Further investigations of the precise interaction of these parameters are necessary for a better understanding of biofilm formation on dental restorations.

In this study, we tested different materials with a biofilm model containing only a single bacterial species. Furthermore, three representative oral pathogens were chosen as test organisms, but the oral cavity is much more complex, so further *in vivo* investigations are necessary.

CONCLUSIONS

Considering all results, the following conclusions can be drawn:

- All of the tested temporary materials lack RO; therefore, it would be interesting to determine if there are any possibilities to alter the composition

of the materials to increase these values so that the practitioner can opt for a higher radiographic visibility if necessary.
- CC materials showed lower values for SR and SFE, thus providing better surface properties for the restorations.
- Conventionally processed temporary materials showed higher and more unsteady values for PA. Therefore, CC temporary materials may be superior to cp materials when used over longer periods of time.

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Conflict of Interest

The authors of this manuscript certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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