Aus der Poliklinik für Zahnärztliche Prothetik

der Ludwig-Maximilians-Universität München

Direktor: Prof. Dr. med. dent. Dr. h.c. Wolfgang Gernet

Langzeitstabilität von CAD/CAM-Kunststoffen

Dissertation

zum Erwerb des Doktorgrades der Humanbiologie

an der Medizinischen Fakultät der Ludwig-Maximilians-Universität zu

München

vorgelegt von

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aus Zabrze/Hindenburg

2013

Mit Genehmigung der Medizinischen Fakultät

der Universität München

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sowie

meinem Mann Frank für zahllose einsame Tage und

seiner großen Geduld mir gegenüber

gewidmet

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1. Einleitung und Zielsetzung

Neben den Keramiken finden in der Zahnmedizin seit einigen Jahren Kunststoffe als zahnfarbene monolithische Rekonstruktionen Anwendung. Dazu werden industriell hergestellte CAD/CAM-Blöcke verwendet, die maschinell bearbeitet werden. Vorteil dieser Kunststoffe ist die Art und Weise der Polymerisation. Im Gegensatz zu konventionell polymerisierten Kunststoffen, die entweder in der Praxis (Direktprovisorien) oder vom Zahntechniker im Labor im Drucktopf (Eierschalenprovisorien) ausgehärtet werden, werden die neuen maschinell zu bearbeitenden Kunststoffe standardisiert zu CAD/CAM-Blöcken polymerisiert. Diese industrielle Polymerisation findet unter hohem Druck und hoher Temperatur statt und führt dazu, dass die physikalischen Eigenschaften der Kunststoffe verbessert werden. Ein weiterer Vorteil dieser industriell polymerisierten Kunststoffe ist die hohe Umsetzungsrate und der daraus resultierende niedrige Restmonomergehalt. Damit wird das Risiko für Patienten allergische Reaktionen zu entwickeln reduziert. Maschinell bearbeitbare Kunststoffe sind durch die Vorteile der industriellen Polymerisation chemisch und allergologisch innert.

Zur Zeit werden CAD/CAM-Kunststoffe für temporäre Versorgungen eingesetzt. Da die CAD/CAM-Kunststoffe im Vergleich zu konventionellen Kunststoffen bessere physikalische Eigenschaften ausweisen, bergen sie das Potential, für definitive Rekonstruktionen verwendbar zu sein. Glaskeramiken werden heute routinemäßig für Einzelrekonstruktionen eingesetzt. Sie haben gute mechanische sowie auch optische Eigenschaften. Ein Nachteil der Keramiken ist das spröde Verhalten, welches teilweise unerwartet zu Frakturen führen kann. Kunststoffe dagegen lassen sich leicht plastisch verformen und weisen daher höhere Bruchzähigkeiten auf. Somit wäre es denkbar, dass die Kunststoffe ähnliche

Indikationsbereiche wie die Glaskeramiken abdecken könnten. Aus diesem Grund war das Ziel dieser Arbeit, die Eigenschaften neu entwickelter CAD/CAM-Kunststoffe zu testen und diese mit Glaskeramiken, als derzeitigen Goldstandard für zahnfarbene Restaurationen, zu vergleichen.

Zu diesem Zweck wurden zusammenfassend innerhalb der vorliegenden Arbeit folgende Punkte untersucht:

a. Langzeitbruchlastverhalten von CAD/CAM Kunststoffen
b. Langzeitverfärbungsraten von CAD/CAM Kunststoffen
c. Abrasionsbeständigkeiten von CAD/CAM Kunststoffen

2. Eigene Arbeit

Nachfolgend werden 3 Originalarbeiten in englischer Sprache vorgestellt und diskutiert.

2.1. Originalarbeit: Stawarczyk B, Ender A, Trottmann A, Özcan M, Fischer J, Hämmerle CHF. Load-bearing capacity of CAD/CAM milled polymeric three-unit fixed dental prostheses: Effect of aging regimens. Clin Oral Investig 2012;16(6):1669-1677.

Zusammenfassung

Ziel: Ziel dieser Untersuchung war es, die Bruchlast von dreigliedrigen CAD/CAM Brücken zu testen und mit Brücken aus konventionellen Kunststoffen sowie Glaskeramik zu vergleichen.

Material und Methode: Es wurden aus vier CAD/CAM-Kunststoffen (artBloc Temp, Telio CAD, ZENO PMMA und CAD-Temp), zwei manuell polymerisierten Kunststoffen (Integral esthetic press und CronMix K) und einer Glaskeramik (IMAGINE PressX) insgesamt 1050 formkongruente dreigliedrige Brücken hergestellt. Die glaskeramischen Brücken bildeten die Kontrollgruppe. Jeweils 15 Prüfkörper jeder Gruppe wurden unmittelbar nach der Herstellung einer Bestimmung der Bruchlast unterzogen. Weitere 75 Prüfkörper pro Gruppe wurden in künstlichem Speichel bei 37°C gealtert. Es wurden nach dem ersten, nach dem 7., 28., 90. und 180. Tag jeweils 15 Prüfkörper aus jeder Gruppe entnommen und deren Bruchlast bestimmt. Die restlichen ungealterten 60 Prüfkörper pro Gruppe wurden im Kausimulator gealtert (bis jeweils 120.000, 240.000, 600.000 und 1.200.000 Kauzyklen, 49 N, 5°C/50°C) und anschließend ebenfalls einer Bruchlastbestimmung zugeführt. Die erzielten Bruchlastwerte wurden mittels 2-way und 1-way ANOVA mit folgendem Scheffé post-hoc Test ausgewertet.

Ergebnisse: Die Interaktion zwischen dem Rekonstruktionsmaterial und der Alterungszeit sowohl bei im künstlichen Speichel gealterten Brücken als auch bei den kausimulierten Brücken zeigte einen signifikanten Einfluss auf die Bruchlastwerte ($p<0.001$). Innerhalb der im künstlichen Speichel gealterten Gruppen wurden bei TelioCAD und ZENO PMMA die höchsten und bei der Glaskeramik die tiefsten Bruchlastwerte gemessen. ArtBloc Temp und CAD-Temp zeigten keinen Einfluss der Kausimulation auf die Bruchlast. TelioCAD, ZENO PMMA und ArtBloc Temp präsentierten in dieser Reihenfolge aufsteigend die höchsten Bruchlasten ($p<0.05$), während Glaskeramik gefolgt von CronMix K die signifikant tiefsten Bruchlastwerte nach der Kausimulation aufwiesen ($p<0.001$).

Schlussfolgerung: Eine künstliche Alterung im Speichel oder in der Kaumaschine zeigte bei CAD/CAM-Kunststoffen keinen Einfluss auf die Bruchlastwerte. Brücken aus Glaskeramik präsentierten signifikant tiefere Bruchlastwerte als alle anderen hier geprüften Kunststoffbrücken.

Klinische Relevanz: Unter dem Aspekt der Bruchlast, ist es möglich, dass die hier getesteten CAD/CAM-Kunststoffe zukünftig zu einer Alternative zu Glaskeramik-Rekonstruktionen werden könnten.

Eigene Arbeit

Clin Oral Invest (2012) 16:1669–1677
DOI 10.1007/s00784-011-0670-4

ORIGINAL ARTICLE

Load-bearing capacity of CAD/CAM milled polymeric three-unit fixed dental prostheses: Effect of aging regimens

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Received: 14 September 2011 / Accepted: 20 December 2011 / Published online: 3 January 2012

Abstract
Objective This study tested the fracture load of milled and conventionally fabricated polymeric and glass-ceramic three-unit fixed dental prostheses (FDPs) after aging.
Materials and methods FDPs were fabricated (N=1,050) from four computer-aided design and computer-aided manufacturing (CAD/CAM) resins: (1) AT (artBlock Temp); (2) TC (Telio CAD); (3) ZP (ZENO PMMA); (4) CT (CAD-Temp); two conventionally fabricated resins, (5) IES (integral esthetic press), (6) CMK (CronMix K), and a glass-ceramic (control) (7) PG (IMAGINE PressX). Specimens of each group were tested immediately after fabrication (n=15 per material). Seventy-five FDPs per material type were stored in artificial saliva (37°C) and 15 of them were randomly selected after aging (1, 7, 28, 90, and 180 days) for fracture load measurement. The remaining specimens (n=60 per material) were subjected to chewing simulation (×120.000–1.200.000, 49 N, 5°C/50°C). The data were analyzed using two-way and one-way ANOVA followed by Scheffé test.
Results The interactions between FDP materials and aging time in both storage media showed a significant impact on the results (p<0.001). Among saliva storage groups, TC and ZP showed the highest, and PG the lowest fracture load (p< 0.05). AT and CT were not affected from chewing simulation. TC, ZP, and AT presented the highest in ascending order (p<0.05), PG and CMK showed the lowest fracture load after chewing simulation (p<0.001).
Conclusions Aging did not influence the fracture load of FDPs made of CAD/CAM resins. FDPs made of glass–ceramic showed significantly lower fracture load than those of all resin FDPs. *Clinical relevance*: Considering fracture load measurements, CAD/CAM resins tested could be alternative materials to glass–ceramic for FDP construction.

Keywords CAD/CAM resins · Resin blanks · Conventionally fabricated resins · FDPs · Fracture load · Aging

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Introduction

Tooth-colored temporary fixed dental prostheses (FDPs) can be constructed and milled from polymeric resin blocks using computer-aided design/computer-aided manufacturing (CAD/CAM) technology [1] either at labside or chairside. Chairside fabricated reconstructions can be cemented at the same session, thus reducing the treatment time, and eliminating the need for making temporary prostheses.

Polymeric blanks for CAD/CAM technology are industrially polymerized under standardized parameters at high temperature and pressure. Hence, microstructure and mechanical properties of the resin blocks exhibit constant quality. This allows for the production of reconstructions with higher flexural strengths compared to conventionally fabricated ones [1, 2]. In general, temporaries are made of chemically cured resins either in powder/liquid (PMMA) or paste form (resin composite). While for direct temporary FDPs, usually, chemically polymerized composites are used; for indirect ones, PMMA-based resins are preferred that are polymerized under pressure in a polymerization device. The polymerization parameters are fundamental for the mechanical properties [3]. However, compared to CAD/CAM milled FDPs, the quality of manually processed ones may be highly affected by the operator.

Glass–ceramic materials for fixed reconstructions require certain thickness to have adequate fracture resistance, whereas resin materials are more fracture-resistant even in thin reconstructions [4, 5]. The wear characteristics of resin-based materials offer some advantages over glass–ceramics as they yield to less wear in the antagonist enamel [6, 7]. Therefore, due to their mechanical properties and brittleness, conventional glass–ceramics are not indicated for multiple unit FDPs, but for single crowns [8]. Therefore, recently introduced polymeric CAD/CAM resins are considered as alternative materials to glass–ceramics. However, limited information is available on their long-term mechanical durability [1, 2].

The aim of this study was to investigate the effect of saliva storage and chewing simulation on the fracture load of conventionally and CAD/CAM fabricated polymeric three-unit FDPs. The first hypothesis tested was whether the CAD/CAM resin FDPs show similar fracture load after aging simulations compared to conventionally fabricated ones. The second hypothesis tested was whether the fracture load of CAD/CAM resin FDPs is higher than glass–ceramic three-unit FDPs.

Materials and methods

This study tested the fracture load of three-unit FDPs fabricated from four different CAD/CAM materials, two manually processed resins and one glass–ceramic (Table 1).

One hundred fifteen identically shaped three-unit FDPs were fabricated from each material. The connectors had a cross-section of 7.36 mm^2, an occlusogingival height of 3.2 mm, and a buccolingual width of 2.3 mm [9]. The occlusal surfaces were kept flat. For the production of the specimens, a steel model with two abutments simulating an FDP between a second premolar and a second molar was used. Abutments of this model were cylindrical (diameter, 7 mm premolar; 8 mm molar) with a 1-mm circular shoulder

Table 1 The tested materials, abbreviations, composition, manufacturer, batch numbers, and manufacturing type of the test groups

Materials	Abbreviations	Composition	Manufacturer	Batch numbers	Manufacturing type
artBlock Temp	AT	PMMA, OMP=organic modified polymer network	Merz Dental, Lütjenburg, Germany	23808	CAD/CAM milling
Telio CAD	TC	99.5% PMMA Polymer	Ivoclar Vivadent, Schaan, Liechtenstein	MM1068	
ZENO PMMA	ZP	PMMA-based	Wieland Dental, Pforzheim, Germany	1309273	
CAD-Temp	CT	Acrylpolymer with 14% micro-filler. MRP= microfilled reinforced polyacrylat	Vita Zahnfabrik, Bad Säckingen, Germany	19180	
Integral esthetic press	IEP	MMA, dimethacrylate, barbituric acid catalyst system, PMMA, organic, and inorganic pigments polymerization: mixing ratio/ powder/liquid 10 g:7 ml mixing time:30 s polymerization: 10 min in the pressure vessel at 45°, and 2.5 bar pressure	Merz Dental, Lütjenburg, Germany	1/4106 55007	Conventional fabrication
CronMix K	CMK	UDMA-based polymerization: auto-polymerization, polymerization time: 7 min	Merz Dental, Lütjenburg, Germany	592308	
IMAGINE PressX	PG	SiO-based glass ceramic	Wieland Dental, Pforzheim, Germany	2/05	Pressing

and 6° taper [9]. They were made of steel to minimize their residual deformation during the loading test and are surrounded by a 0.5-mm layer of plastic cover that allowed for simulation of the periodontium [10, 11]. The holder of the test setup was made of an aluminum alloy having cylindrical holes of 7.8 and 8.8 mm diameter and a distance of 16.5 mm between centers of the holes.

The CAD/CAM resins (N=600, n=150 per material) and 150 wax blanks (ZENO TEC Wax Disc, Wieland Dental, Pforzheim, Germany) for the press ceramic FDPs were milled using a master STL-file of a three-unit FDP. The Cerec inLab system (Sirona, Bensheim, Germany) was used for AT, TC, and CT, while the ZENO Tec System (ZENO 4030 M1, Wieland Dental) was employed for ZP and the wax templates.

Subsequently, for the glass–ceramic specimens, the wax templates were invested (Wilavest Universal, Wieland Dental) according to the manufacturer's instructions. After evaporating the wax in a standard oven (EWL Type 5636, KaVo, EWL, Leutkirch, Germany), the PG specimens were pressed in a special oven (EP 600, Ivoclar Vivadent, Schaan, Liechtenstein). The investment material was removed after cooling in an air abrasion unit (CEMAT NT4, Wassermann, Hamburg, Germany) using 50-μm alumina particles (Renfert, Hilzingen, Germany) at 2 bar pressure. Finally, glaze paste was applied on the crowns and fired in a ceramic oven (Astromat D4, DEKEMA, Freilassing, Germany).

For the conventionally fabricated FDPs, one silicone key with a standard shape and size was used. The manually polymerized resins were filled in the silicone key and polymerized according to the respective manufacturer's instructions (Table 1). The surface of direct temporary FDPs (CMK) was ground with a fine polish brush (Soft PD H DT2, Pluradent, Offenbach, Germany). In order to simulate the clinical environment, the indirect temporary FDPs (IEP) were relined with a PMMA resin (TAB 2000, Lot.No: 61565, Kerr, Bioggio, Switzerland) and polymerized according to the manufacturer's instruction (Table 1). Thereafter, the final indirect temporary FDPs were finished and polished.

The fabricated FDPs of each material (n=150) were then randomly divided into three groups; FDPs for direct measurements (n=15), for saliva storage (n=75), and for chewing simulation (n=60).

Saliva storage

The FDPs were stored in artificial saliva (Fusayama/Meyer: KCl 0.4 g/l, NaCl 0.4 g/l, $CaCl_2$, $2H_2O$ 0.906 g/l, NaH_2PO_4, $2H_2O$ 0.690 g/l, Na_2S, $9H_2O$ 0.005 g/l, and urea 1 g/l; pH= 4.7) at 37°C in an incubator (ED 240; Binder; Tuttlingen, Germany). Fifteen specimens were randomly selected after 1, 7, 28, 90, and 180 days for fracture load measurements.

Chewing simulation

Chewing simulation (custom made: University of Zurich) with thermal cycling (5°C/50°C; transfer time, 10 s; dwell time, 120 s) was performed for 120,000, 240,000, 640,000, and 1,200,000 masticatory cycles [12]. The FDPs were loaded under 49 N at a frequency of 1.67 Hz. For simulating a typical clinical situation, mesiobuccal cusp from nearly identical maxillary human molars, fixed in amalgam (Dispersalloy; Dentsply; Konstanz, Germany), acted as antagonists. The tips of the cusps were rounded to a spherical shape. The horizontal distance between FDP and the enamel antagonist was 3 mm. After chewing simulation, the specimens were subjected to fracture load testing.

Fracture load measurement

The fracture load test was performed in a universal testing machine (Zwick/Roell Z010, Zwick, Ulm, Germany). The FDPs were placed on the abutments without using cement and loaded with a flat-ended rod (diameter 5 mm) at the center of the pontic from the occlusal–gingival direction until fracture occurred (crosshead speed 1 mm/min) (Fig. 1). In order to avoid force peaks, a piece of 0.3-mm teflon foil (Angst+Pfister, Zurich, Switzerland) was placed between the pontic and the loading jig.

Statistical analysis

The fracture load data were analyzed using a statistical software program (SPSS version 19, SPSS Inc., Chicago, IL, USA). Initially, the descriptive statistics were computed. Two-way and one-way ANOVA followed by Scheffé post-hoc test were used for the analysis of fracture load data for saliva-stored and chewing-simulated FDPs. The fracture load of specimens that fractured during the chewing simulation before actual testing was considered as 0 N. In all

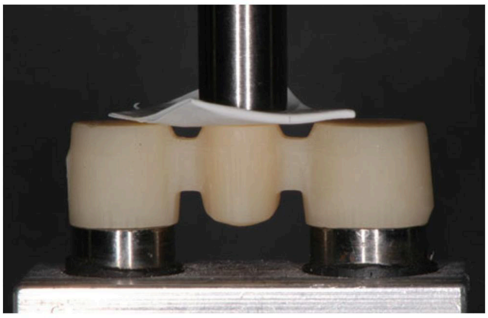

Fig. 1 FDP on the steel model during fracture load measurement

Table 2 Two-way ANOVA results for comparison of fracture load after different saliva storage times and different FDPs materials

	Sum of squares	*df*	Mean squares	*F*	*p* value
Constant parameters	74,132,501	1	74,132,501	38,689	<0.001
FDP material	5,415,929	6	902,655	471	<0.001
Saliva storage days	80,832	5	16,166	8	<0.001
FDP material × saliva storage	1,194,781	30	39,826	21	<0.001
Error	1,126,683	588	1,916		
Total	81,950,726	630			

tests, *p*-values smaller than 5% were considered as statistically significant.

Results

Saliva storage

The two-way interaction (FDP materials versus aging) was significant ($p<0.001$). Also, the interactions between FDP materials and aging time showed significant impact on the results ($p<0.001$). Therefore, the fixed effects FDP materials and aging cannot be compared directly as the higher order interactions were found to be significant. Consequently, several different analyses were provided and splitted at levels of FDP materials and aging factors depending on the hypothesis of interest (Table 2). The results of the descriptive statistics (mean, SD, 95% CI) with one-way ANOVA results for the fracture load of each tested group are presented in Table 3.

Table 3 Descriptive statistics of fracture load after different saliva storage times and different FDPs materials

	Initial	1 day	7 days	28 days	90 days	180 days
AT						
Mean (SD)	384^{bc} $(17)^{zy}$	384^{b} $(24)^{z}$	377^{cd} $(48)^{zy}$	375^{cd} $(30)^{zy}$	349^{b} $(20)^{zy}$	348^{b} $(24)^{y}$
95% CI	(374, 394)	(370, 398)	(349, 404)	(357, 392)	(337, 358)	(333, 362)
Min, max	359, 408	348, 423	328, 539	348, 473	320, 387	289, 393
TC						
Mean (SD)	420^{b} $(58)^{z}$	445^{a} $(56)^{z}$	399^{bc} $(32)^{z}$	404^{bc} $(14)^{z}$	434^{a} $(38)^{z}$	411^{a} $(46)^{z}$
95% CI	(387, 453)	(413, 477)	(380, 417)	(394, 412)	(412, 456)	(384, 437)
Min, max	329, 541	318, 501	324, 436	366, 428	378, 513	324, 464
ZP						
Mean (SD)	467^{a} $(21)^{z}$	461^{a} $(48)^{z}$	453^{ab} $(68)^{z}$	452^{ab} $(76)^{z}$	450^{a} $(59)^{z}$	437^{a} $(72)^{z}$
95% CI	(454, 479)	(433, 488)	(414, 491)	(409, 495)	(416, 483)	(396, 478)
Min, max	429, 505	379, 563	299, 582	284, 593	377, 568	274, 544
CT						
Mean (SD)	289^{d} $(30)^{z}$	290^{d} $(16)^{z}$	297^{e} $(21)^{z}$	277^{e} $(9)^{z}$	284^{c} $(19)^{z}$	298^{bc} $(18)^{z}$
95% CI	(272, 306)	(279, 299)	(284, 309)	(270, 283)	(272, 295)	(286, 308)
Min, max	227, 336	273, 341	258, 343	261, 290	239, 313	265, 323
IEP						
Mean (SD)	354^{c} $(40)^{z}$	348^{bc} $(50)^{z}$	319^{de} $(47)^{zy}$	318^{de} $(42)^{zy}$	302^{bc} $(49)^{zy}$	268^{c} $(35)^{y}$
95% CI	(332, 377)	(319, 377)	(292, 346)	(293, 342)	(274, 330)	(247, 288)
Min, max	305, 456	282, 457	229, 402	249, 401	208, 403	200, 320
CMK						
Mean (SD)	180^{e} $(34)^{w}$	323^{cd} $(58)^{x}$	509^{a} $(41)^{z}$	480^{a} $(59)^{zy}$	434^{a} $(77)^{y}$	452^{a} $(42)^{zy}$
95% CI	(161, 200)	(289, 356)	(485, 532)	(446, 513)	(389, 477)	(427, 476)
Min, max	134, 244	157, 379	408, 579	357, 530	264, 541	329, 517
PG						
Mean (SD)	160^{e} $(22)^{z}$	153^{e} $(34)^{z}$	154^{f} $(47)^{z}$	155^{f} $(47)^{z}$	157^{d} $(51)^{z}$	153^{d} $(47)^{z}$
95% CI	(147, 172)	(133, 173)	(126, 180)	(128, 182)	(128, 186)	(125, 180)
Min, max	121, 195	100, 244	79, 285	78, 274	93, 288	76, 244

The letters zyx in superscript reflect significant differences within the same FDP material and among saliva storage times according to one-way ANOVA ($p<0.05$). The letters abc in superscript reflect significant differences within the same saliva storage time and within the tested FDPs materials according to one-way ANOVA ($p<0.05$)

The control group, PG, and three of the CAD/CAM fabricated FDPs—TC, ZP, and CT—were not significantly affected by saliva storage up to 180 days (Fig. 2). The CAD/CAM resin AT presented significantly higher fracture load after 1-day storage compared to 180 days of storage ($p < 0.001$). In contrast, the indirect temporary FDPs made of IEP ($p<0.001$) and direct temporaries made of CMK ($p < 0.001$) were significantly affected by saliva storage. Fracture load of IEP decreased significantly after 180 days compared to initial values or after 1-day saliva storage. The mean fracture load of CMK increased up to 7 days of storage ($p<0.001$), but after this time point, the results decreased. After 7 days, the values were significantly higher compared to 90 days of storage ($p<0.05$).

The CAD/CAM resin FDPs AT, TC, and ZP showed the highest fracture load, followed by indirect temporary resin IEC. From the CAD/CAM resin FDPs, CT presented significantly lower values compared to the remaining CAD/CAM resins and conventional resin, IEP ($p<0.05$). The lowest values were observed for the control group at all time points. The direct resin, CMK, showed initially similar values to the glass–ceramic tested, but after 1 day up to 180 days of storage, CMK showed higher values than the glass–ceramic.

Chewing simulation

The two-way interaction (FDP materials versus aging) was significant ($p<0.001$). Also, the interactions between FDP materials and aging time showed a significant impact on the results ($p<0.001$). Therefore, the fixed effects FDP materials and aging cannot be compared directly as the higher order interactions were found to be significant. Consequently, several difference analyses were provided and splitted at levels of FDP materials and aging factors depending on the hypothesis of interest (Table 4). The results of the descriptive statistics (mean, SD, 95% CI) with 1-way ANOVA results for the fracture load of each tested group are presented in Table 5.

Only two FDP materials, namely CAD/CAM resins AT ($p=0.717$) and CT ($p=0.255$), were not affected from chewing simulation (Fig. 3). Among the CAD/CAM resins a significant decrease was observed after 1,200,000 masticatory cycles for ZP ($p<0.001$) (one FDP was fractured) and after 120,000 cycles for TC ($p<0.001$).

The conventional resin IEC ($p<0.001$) and the control group ($p<0.001$) showed decreased fracture load with the increase in the number of masticatory cycles. The fracture load of CMK increased after 120,000 cycles and then decreased with the increase in masticatory cycles, and after 640,000 cycles, all specimens were fractured during the chewing simulation. In the group IEP, 1, 2, 6, and 12 specimens were fractured after 120,000, 240,000, 640,000, 1,200,000 cycles, respectively. In CMK group, 4, 15, and 15 specimens were fractured after 240,000, 640,000, and 1,200,000 cycles, respectively. The control group showed 2 fractured FDPs after 240,000, 8 fractured FDPs after 640,000, and 15 fractured FDPs after 1,200,000 cycles (Table 6).

All tested FDPs fractured typically between the abutment and the pontic at the connector area.

Discussion

In general, the results of this study showed that storage in saliva and chewing simulation did not influence industrially polymerized CAD/CAM resins, except ZP, compared to indirect or direct temporary FDPs tested. Therefore, the first hypothesis of this study is rejected. By industrially polymerizing CAD/CAM resins under optimal conditions, the mechanical strength is increased and the risk for porosities within the restorations is reduced [13]. In contrast, the

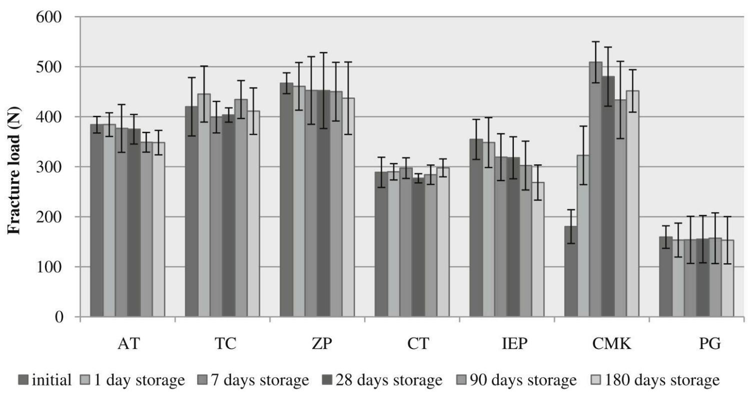

Fig. 2 Mean fracture load with standard deviation of all tested FDPs after different saliva storage levels

Eigene Arbeit

Table 4 Two-way ANOVA results for comparison of fracture load after different masticatory cycles and different FDPs materials

	Sum of squares	*df*	Mean squares	*F*	*p* value
Constant parameters	37,549,368	1	37,549,368	11632	<0.001
FDP material	7,631,036	6	1,271,839	394	<0.001
Masticatory cycles	1,304,379	4	326,095	101	<0.001
FDP material × masticatory cycles	1,272,342	24	53,014	16	<0.001
Error	1,581,826	490	3,228		
Total	49,338,949	525			

mechanical properties of conventionally fabricated resin FDPs are dependent on the operator, mixing proportions of the resin components, polymerization device, and duration of the polymerization, among others.

In this study, glass–ceramic was used as control group. Glass–ceramic is the most commonly used material for CAD/CAM single crowns and inlays or onlays. The glass–ceramic FDPs presented the lowest values compared to all tested CAD/CAM resins. Consequently, the second hypothesis is accepted.

After 1-day saliva storage at 37°C, the direct temporary resin tested in this study (CMK) showed an increase in fracture load values, probably due to post-polymerization of the monomer. In another study, similar results were obtained initially and 1 day after storage [14]. In this study, after 1-day storage in saliva and chewing simulator, the fracture load increased for CMK. Burtscher [15] reported that radicals may be active over a period of 7 days, leading to a significant post-polymerization. The results of this study with CMK support this statement when the results

Table 5 Descriptive statistics of fracture load after different masticatory cycles (MC) and different FDPs materials

	Initial	120,000 MC	240,000 MC	640,000 MC	1,200,000 MC
AT					
Mean (SD)	384^{bc} (17)^{z}	380^{ab} (18)^{z}	377^{ab} (24)^{z}	371^{b} (32)^{z}	381^{a} (33)^{z}
95% CI	(374, 394)	(368, 391)	(362, 390)	(352, 390)	(361, 400)
Min, max	359, 408	350, 427	346, 437	300, 427	324, 473
TC					
Mean (SD)	420^{b} (58)^{z}	365^{ab} (47)^{y}	372^{ab} (60)^{zy}	342^{b} (29)^{y}	351^{a} (30)^{y}
95% CI	(387, 453)	(337, 391)	(338, 406)	(324, 358)	(333, 367)
Min, max	329, 541	291, 456	294, 475	294, 392	299, 397
ZP					
Mean (SD)	467^{a} (21)^{z}	435^{a} (40)^{z}	436^{a} (39)^{z}	444^{a} (51)^{z}	350^{a} (125)^{y}
95% CI	(454, 479)	(411, 458)	(413, 458)	(414, 473)	(279, 420)
Min, max	429, 505	368, 512	365, 501	345, 516	0, 527
CT					
Mean (SD)	289^{d} (30)^{z}	268^{c} (48)^{z}	269^{c} (34)^{z}	265^{c} (38)^{z}	247^{b} (81)^{z}
95% CI	(272, 306)	(240, 295)	(248, 288)	(242, 286)	(201, 292)
Min, max	227, 336	176, 370	194, 332	168, 303	0, 363
IEP					
Mean (SD)	354^{c} (40)^{z}	317^{bc} (110)^{z}	297^{bc} (125)^{z}	86^{d} (75)^{y}	15^{c} (36)^{y}
95% CI	(332, 377)	(255, 378)	(226, 367)	(43, 128)	(−5, 35)
Min, max	305, 456	0, 426	0, 397	0, 173	0, 121
CMK					
Mean (SD)	180^{e} (34)^{y}	248^{c} (55)^{z}	128^{d} (90)^{y}	0^{e} (0)^{x}	0^{c} (0)^{x}
95% CI	(161, 200)	(216, 279)	(77, 178)	–	–
Min, max	134, 244	165, 299	0, 263	0, 0	0, 0
PG					
Mean (SD)	160^{e} (22)^{z}	147^{d} (35)^{zy}	136^{d} (71)^{zy}	82^{d} (96)^{y}	0^{c} (0)^{x}
95% CI	(147, 172)	(125, 167)	(95, 176)	(27, 135)	–
Min, max	121, 195	89, 217	0, 281	0, 283	0, 0

The letters zyx in superscript reflect significant differences within same FDP material and among masticatory cycles according to one-way ANOVA ($p<0.05$). The letters abc in superscript reflect significant differences within same masticatory cycle and within the tested FDPs materials according to one-way ANOVA ($p<0.05$)

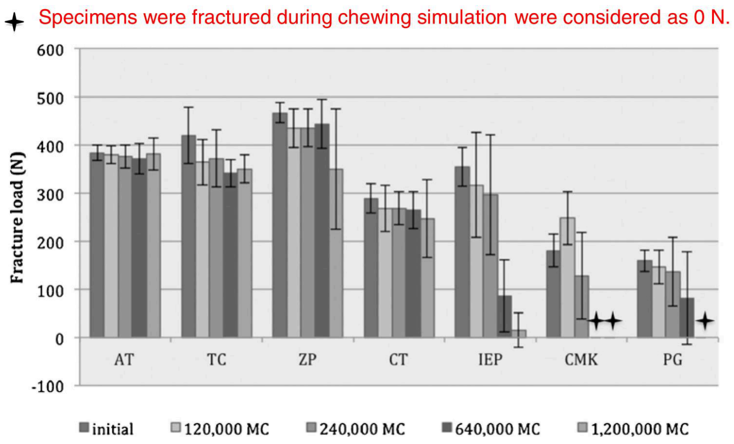

Fig. 3 Mean fracture load with standard deviation of all tested FDPs after different masticatory cycles

up to 7 days are considered. This can, however, be stated only for saliva storage. With CMK in the chewing simulator, the results showed some post-polymerization possibility between initial and 1 day.

The specimens were subjected to chewing simulation, where the stress for all specimens was standardized and reproducible. The use of a loading machine with additional artificial aging by thermocycling is a well-proven and established method to simulate the clinical situation [16, 17]. It is claimed that the chewing simulation of 1,200,000 cycles corresponds to 5 years in vivo [18]. However, this assumption has not yet been systematically verified with different materials and is only based on the extrapolation of 4-year clinical wear data on amalgam fillings and 6-month data of composite inlays [18]. Thus, the correlation was only used for the measurements of abrasion stability. In summary, more longitudinal clinical aging data are still needed. At the time, only trends and indications as to the true extent of aging can be obtained.

The setup with the steel model used could have a negative impact on the fracture load results. It has been previously reported, that the mean fracture loads of FDPs decrease on rigidly mounted abutments compared to non-rigidly mounted ones [19, 20]. The authors reported that the elastic modulus of the abutment had an influence on the fracture load of FDPs [19, 20]. Another study showed that increasing the elastic modulus of the abutments results in increased fracture load [21]. Non-rigidly mounted abutments with an elastic modulus similar to that of natural teeth behave similarly to the clinical situation [2, 22]. In addition, in this study, the FDPs were not cemented on the abutment. Possible effect of cement use should be further investigated since lack of cement might have created inferior bending forces and less damping effect.

The FDP design had flat occlusal surfaces, not representing the real clinical situation. The lack of veneering materials and occlusal morphology are limitations of this study. Therefore, this study serves for only ranking the materials. Further studies should test these aspects as well. In the present study, the connector area of the FDPs was 7.36 mm^2. The manufacturer of artBlock Temp recommends 9 mm^2 and of CAD-Temp 12 mm^2; those are higher section area than employed here. Clinically, such a large surface area may jeopardize the periodontal tissues. Therefore, in this study, FDPs had a smaller connector surface area. An increased connector surface area may surely increase the results [23].

Constant clinical occlusal forces of 12 to 90 N and occasional maximum forces up to 909 N in posterior areas

Table 6 Number of fractured FDPs during chewing simulation

	After 120,000 MC	After 240,000 MC	After 640,000 MC	After 1,200,000 MC
AT	–	–	–	–
TC	–	–	–	–
ZP	–	–	–	1
CT	–	–	–	–
IEP	1	2	6	12
CMK	–	4	15	15
PG	–	2	8	15

can be assumed depending on the type of measurement, gender, restoration type, diet, and other parameters [24]. Therefore, failures of the tested FDPs were observed below 500 N. Thus, the fracture load tested in this study may not withstand the clinical applications without restrictions.

Fasbinder et al. [25] studied the clinical performance of CAD/CAM fabricated composite inlays and observed that the resin-based composite inlays had a significantly better color match at 3 years than did the glass–ceramic inlays. Resin-based composite CAD/CAM inlays performed as good as glass–ceramic CAD/CAM inlays after 3 years of clinical service. Lehmann et al. [26] observed clinical failures and complications such as wear facet, plaque accumulation in single resin composite crowns after 5 years. They concluded that composite crowns might be recommended for long-term temporary use. However, the complication rate and the increased plaque accumulation may restrict the indication for permanent restorations. Vanoorbeek et al. [27] in a clinical study up to 3 years of function observed that resin composite single-tooth restorations had inferior success rates compared to all-ceramic ones. Due to the inferior esthetics and wear resistance of resin composite crowns, all-ceramic crowns remain the preferred treatment material for CAD/CAM-generated metal-free single restorations. Future developments with PMMA- or composite-based FDPs should concentrate on improvement of wear stability of such materials that could still be considered inferior to glass–ceramics.

Based on the findings after chewing simulation, CAD/CAM resins have obvious advantages over conventionally fabricated ones. However, clinical studies are needed to support the use of CAD/CAM resins in long-term restorations.

Conclusions

Within the limitations of this study, the following conclusions can be drawn:

1. The tested CAD/CAM resin FDPs, with the exception of ZP, were not influenced by storage in saliva and chewing simulation compared to conventionally fabricated ones.
2. CAD/CAM resins—AT, TC, and ZP—presented higher fracture load compared to CAD/CAM resin CT.
3. Glass–ceramic three-unit FDPs showed lower mean fracture load compared to the tested manually and CAD/CAM fabricated resin FDPs.

Acknowledgments We are grateful to Merz Dental, Vita Zahnfabrik, Ivoclar Vivadent, and Wieland Dental for the financial and material support.

Conflict of interest The authors declare no conflicts of interest.

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2.2. Originalarbeit: Stawarczyk B, Sener B, Trottmann A, Roos M, Özcan M, Hämmerle CHF. Discoloration of manually fabricated resins and industrially fabricated CAD/CAM blocks versus glass-ceramic: Effect of storage media, duration, and subsequent polishing. Dent Mater J 2012;31(3):377-383.

Zusammenfassung

Ziel: Diese Studie untersucht die Farbbeständigkeit von CAD/CAM-Kunststoffen und vergleicht diese mit konventionellen Kunststoffen und Glaskeramik.

Material und Methode: Aus fünf CAD/CAM-Kunststoffen (Blanc High-class, ZENO PMMA, artBloc Temp, artegral ImCrown und CAD-Temp), vier konventionellen Kunststoffen (Unifast III, Gradia, CronMix K und Integral esthetic press) und einer Glaskeramik (empress CAD) wurden jeweils 30 runde Prüfkörper mit einem Durchmesser von 15 mm und der Dicke von 2 mm hergestellt. Anschließend wurden die 30 Prüfkörper pro Material randomisiert in jeweils 3 Gruppen a 10 Prüfkörper aufgeteilt, um sie in Tee, Kaffee oder Rotwein bis zu 180 Tagen zu altern. Bei allen Prüfkörpern wurde jeweils initial (Baseline), nach einem Tag, nach 7, 28, 90 und 180 Tagen die Verfärbungsrate gemessen. Nach der letzten Messung wurden die Prüfkörper mit einer Politurpaste (Cleanic) parallel zum klinischen Vorgehen poliert und dann erneut die Verfärbungen vermessen. Aus den gemessenen Werten wurde die Farbveränderung ΔE berechnet. Neben den deskriptive Statistiken, wurde der Einfluss des Materials sowie der Lagerungszeit mittels der linearen Regression der gemischten Modelle, mit Glaskeramik als Baseline, analysiert. Im gepaarten t-Test wurde die Verfärbungsrate nach der Politur mit der vor der Alterung verglichen ($p<0.05$).

Ergebnisse: Alle in dieser Studie getesteten Gruppen wiesen in allen Lagerungsflüssigkeiten Verfärbungen (ΔE) auf ($p<0.001$). Die Verfärbungen nahmen mit der Lagerungszeit zu ($p<0.001$). In allen drei Flüssigkeiten zeigten die manuell polymerisierten Komposite (Gradia und CronMix C) sowie der CAD/CAM Blanc High-class Komposit signifikant höheren Verfärbungsraten als die PMMA-basierten Materialien. Mit Ausnahme von Blanc High-class war die Verfärbungsrate der CAD/CAM Kunststoffe vergleichbar mit der Verfärbungsrate der Glaskeramik.

Schlussfolgerung: Alle in dieser Untersuchung getesteten PMMA-basierte CAD/CAM-Kunststoffe zeigten ähnliche Farbstabilitäten wie Glaskeramik.

Klinische Relevanz: Unter dem Aspekt der Farbstabilität ist es möglich, dass die hier getesteten PMMA-basierte CAD/CAM-Kunststoffe in der Zukunft eine Alternative zu Glaskeramik-Rekonstruktionen werden könnten.

Dental Materials Journal 2012; 31(3): 377–383

Discoloration of manually fabricated resins and industrially fabricated CAD/CAM blocks *versus* glass-ceramic: Effect of storage media, duration, and subsequent polishing

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This study determined the discoloration of five CAD/CAM resins, four manually polymerized resins, and glass-ceramic as control group. Specimens were divided into three groups (N=300, n=30) to be stored in coffee, black tea and red wine (n=10). The discoloration was measured using a spectrophotometer after 1, 7, 29, 90, 180 days storage. All tested groups showed color change (ΔE) at all time points. The manually polymerized resin composites GD (Gradia) and CM (CronMix K), and the CAD/CAM resin composite HC (Blanc High-class) showed significantly higher ΔE compared to all other groups in all tested media. The discoloration was extrinsic and decreased after polishing for the majority of the tested materials. Except CAD/CAM resin HC (Blanc High-class), all CAD/CAM resins showed similar color stability compared to the control group.

Keywords: CAD/CAM resins, Polymeric blocks, Discoloration, Aging

INTRODUCTION

The CAD/CAM milling of resin blocks for temporary fixed dental prostheses (FDPs) fabricated under controlled and optimized manufacturing conditions enables the production of reconstructions with higher flexural strengths than those of manually polymerized ones[1-3]. Such CAD/CAM resin blocks are industrially polymerized under standardized parameters at high temperature and pressure to assure that the microstructure and the mechanical properties of the resin blocks exhibit constant quality. The polymerization parameters are fundamental for the mechanical properties[4]. Hence, the resin CAD/CAM blocks can be considered for long-term reconstructions. Industrially or manually polymerized temporaries are made of either PMMA-based or composite resins, each having slightly different chemical and physical properties[5].

Resin restorations are more fracture resistant than glass-ceramics[3], especially in thin reconstructions[6,7]. The mechanical properties such as flexural strength and enamel antagonist wear characteristics of resin-based materials offer some advantages over glass-ceramics[8-10]. Therefore, recently introduced CAD/CAM resin blocks are considered as alternative materials to glass-ceramics. However, one clinical study up to 3 years of function observed that resin single-tooth restorations had inferior success rates compared to all ceramic ones[11]. This was due to the inferior esthetics and wear resistance of resin crowns. Therefore the authors stated that all-ceramic crowns remain the preferred treatment material for CAD/CAM-generated metal-free single restorations. Discoloration still seem to be the limitary factor for resin based materials.

FDP materials must maintain long-term color stability in order to avoid replacement of restorations. Regardless of their chemical composition, dental resins tend to absorb liquids[12]. Therefore, discoloration may occur over time when subjected to various media, such as coffee, tea, red wine, chlorhexidine or bleaching agents[13-16]. Color differences (ΔE) more than 3.3 units reflect clinically significant visual discoloration[17,18]. The degree of discoloration of resins can be influenced by a number of factors such as incomplete polymerization, water sorption, chemical reactivity, diet, oral hygiene or surface roughness of the restoration[19-21]. Discoloration can be due to extrinsic or intrinsic cause. Extrinsic causes include accumulation of plaque and surface stains, alterations of surface or subsurface color, implying a superficial degradation or a slight penetration and reaction of staining agents within the superficial layer of resin composites[22]. Subsequent polishing of the surface in particular can eliminate extrinsic causes, but if deeper layers are involved, the discoloration is mostly irreversible. The intrinsic discolorations mainly depend on the system of initiator systems used in the resins as well as on the applied form and duration of polymerization[23,24]. They are caused by chemical changes in the material matrices and therefore concern all layers of the material.

Various techniques have been employed to elicit discoloration of temporary resins[15,25-33]. Accelerated

Received Nov 15, 2011: Accepted Feb 3, 2012
doi:10.4012/dmj.2011-238 JOI JST.JSTAGE/dmj/2011-238

aging has been used to study the effect of a discoloration on both PMMA-based and composite resins demonstrating that clinically perceptible discoloration are likely to occur in some of the tested resins[26,27,30,32]. Other studies have used immersion solutions such as artificial saliva, coffee, tea, grape juice, and chlorhexidine and at different time intervals compared their effects on discoloration of temporaries and direct restorative resins[15,26,30,31]. To the author's best knowledge at present there is no information on the clinical and laboratory discoloration of the newly introduced CAD/CAM resin reconstructions.

Therefore, the purpose of this study was to evaluate the effect of coffee, black tea and red wine storage on discoloration of five CAD/CAM and four manually polymerized resins, and to compare the results obtained with the control group (glass-ceramic). The first hypothesis was to test whether the CAD/CAM resins show similar discoloration compared to glass-ceramic. The second hypothesis was to test whether the CAD/CAM resins show lower discoloration compared to manually polymerized ones.

MATERIALS AND METHODS

This study included five CAD/CAM resins: Blanc High-class (HC), ZENO PMMA (ZP), artBloc Temp (AT), artegral ImCrown (AI) and CAD-Temp (CT), four manually polymerized resins: Unifast III (UF), Gradia (GD), CronMix K (CM) and Integral esthetic press (IE) and one glass-ceramic empressCAD (CG) as control group (Table 1).

Specimens were prepared (N=300, n=30 per material group) with a diameter of 15 mm and a thickness of 1 mm, following the ISO 4049 specification. A plastic split ring that rested on a glass plate was used to fabricate the manually polymerized specimens. The resins were filled into the split ring between two glass plate and polymerized. UF and IE were polymerized in the polymerization pressure pot (30 min, 45°C, 2.5 min, Ivomat, Ivoclar Vivadent, Schaan, Liechtenstein) according to the manufacturer's instructions. For GC, the GC LaboLight LV-III (GC Europe, Leuven, Belgium) was used for a polymerization time of 5 min according to the manufacturer. The CAD/CAM blocks were cut in disks with a thickness of 1 mm using a low-speed diamond saw (Well Diamantdrahtsägen, Mannheim, Germany) under water-cooling. Thereafter the edges were rounded using a dental bur (Komet H251 EF, Gebr. Brasseler, Lemgo, Germany). All specimens were embedded in acrylic resin (ScandiQuick, SCAN-DIA, Hagen, Germany) in cylindrical molding cups with a diameter of 25 mm.

The specimen surfaces were polished for 4.5 min (P400, P1200, P2400) in a polishing device (LaboPol-21, Struers, Ballerup, Denmark) under standardized conditions and examined under an optical microscope

Table 1 The test groups, abbreviations, brands, batch numbers, manufacturers and composition of the tested materials

Test group	Abbreviation	Batch No.	Manufacturer	Composition
Blanc High-class	HC	2007000908	Creamed, Marburg, Germany	Bis-GMA, UDMA, nanofilled
ZENO PMMA	ZP	0483	Wieland Dental + Technik, Pforzheim, Germany	PMMA, unfilled
artBloc Temp	AT	13708	Merz Dental, Lütjenburg, Germany	PMMA, unfilled
artegral ImCrown	AI	2275	Merz Dental, Lütjenburg, Germany	PMMA, unfilled
CAD-Temp	CT	19180	Vita Zahnfabrik, Bad Säckingen, Germany	PMMA, micro-filled
Unifast III	UF	0709103 0909041	GC Europe. Leuven, Belgium	PMMA, unfilled
Gradia	GD	0809032	GC Europe. Leuven, Belgium	UDMA, EDMA, fine-hybrid filled
CronMix K	CM	592308	Merz Dental, Lütjenburg, Germany	UDMA, HEMA, filled
Integral esthetic press	IE	1/4106 2X2216	Merz Dental, Lütjenburg, Germany	PMMA, unfilled
Empress CAD	GC	JM0355	Ivoclar Vivadent, Schaan, Liechtenstein	SiO_2, BaO, Al_2O_3, CaO, CeO_2, Na_2O, K_2O, B_2O_3, TiO_2

Bis-GMA: bisphenol-A-glycidyl methacrylate; UDMA: urethan dimethacrylate, PMMA: polymethyl methacrylate, EDMA: ethylen glucol dimethylmethacrylate, HEMA: 2-hydroxyethyl methacrylate.

(25×, Wild M3B, Heerbrugg, Switzerland). Each material group was randomly divided in three subgroups: (1) storage in coffee (Mastro Lorenzo Classico, Kraft Foods, Glattpark, Switzerland) at 37°C (n=10), (2) storage in black tea (Lipton Yellow Label, Unilever, Thayngen, Switzerland) at 37°C (n=10), and (3) storage in red wine (Rioja, Spain) at 37°C (n=10).

The discoloration of each specimen was measured before aging and after 1, 7, 28, 90 and 180 days storage. The initial measurement of each group was considered as baseline measurements. The measurements were performed with a calibrated (white standard SRS-99-010-7698-a) spectrophotometer (CM-508d, Minolta, Tokyo, Japan). The resulting parameters (L, a, b) were examined by illuminant D65 using the software (SpectraMagic, Minolta). Then the ΔE-values were calculated with the following formula: $\Delta E=\sqrt{\Delta a^2+\Delta b^2-\Delta L^2}$ (ΔE: general difference in color changes, Δa: difference in color change in the red-green-axis, Δb: difference in color change in the yellow-blue-axids, ΔL: difference in brightness). After 180 days of storage in coffee, black tea and red wine, all specimens were polished for 60 s with a prophylaxis paste (Cleanic, KerrHawe SA, Bioggio, Switzerland) and the color was measured again.

Statistical analysis

Descriptive statistics (mean, SD) were computed. Linear mixed models with baseline of glass-ceramic were applied to investigate the influence of the material, storage time and the interaction between them for all three storage mediums separately. The paired t-test was applied in order to evaluate the impact of polishing compared to specimens stored for 180 days. The Statistical Package for the Social Science Version 19 (SPSS INC, Chicago, IL, USA) was used. All results with p-values less than 5% (p<0.05) were considered as statistically significant.

RESULTS

Descriptive statistics (mean, SD) of the measured discoloration (ΔL, Δa, Δb, ΔE) at all aging levels stored in coffee, black tea or red wine of each tested resin and the control group is presented in Table 2.

One CAD/CAM composite HC and two manually polymerized resin composites GD and CM showed initially higher ΔE in coffee storage compared to the control group (p≤0.002). Significantly higher increase in ΔE in coffee storage was observed for the manually polymerized resins GD and CM than for the control group (p≤0.015). Significantly less increase in ΔE was obtained for the control group compared to the PMMA-based CAD/CAM resins AT and CT (p≤0.028) (Fig. 1).

Among the black tea storage groups, the CAD/CAM resins HC and AT and the manually polymerized resin composite GD showed initially significantly higher ΔE compared to the control group (p≤0.027). CAD/CAM

Table 2 Descriptive statistics for discoloration (ΔE) at each time point for all tested groups and paired t-test p-values for the effect of polishing

Test material	Aging level (days)	mean±SD		
		coffee	Black tea	Red wine
HC	1	3.52±1.9	3.25±1.6	3.87±2.4
	7	5.99±2.3	3.14±2	7.6±3.7
	28	6.91±3.5	4.47±2.3	9.83±3.9
	90	7.08±3.6	8.97±3	19.27±6.7
	180	7.34±3.7	14.04±3.1	21.6±6
	t-test	<0.001	0.096	<0.001
	After polishing	4.42±3.2	12.04±4	5.2±3.2
ZP	1	0.9±1	0.74±0.5	1.28±0.3
	7	1.11±1	1.09±0.4	2.1±0.3
	28	1.55±0.7	1.57±0.5	1.5±0.4
	90	1.09±0.8	1.52±0.5	2.24±0.7
	180	1.17±0.8	1.81±0.6	1±0.1
	t-test	0.091	0.026	0.536
	After polishing	1.66±0.9	1.3±0.8	0.94±0.3
AT	1	3.96±2.1	2.5±2.1	1.29±1.5
	7	2.19±0.5	1.97±1.8	2.17±1.5
	28	2.9±2.8	2.73±2.5	2.36±2.3
	90	1.91±0.7	1.79±1.5	2.89±1.9
	180	1.77±0.9	2.26±2.1	1.2±0.5
	t-test	0.004	0.001	0.053
	After polishing	2.77±1.6	3.23±2.1	0.69±0.4

Table 2 (continued)

Test material	Aging level (days)	mean±SD		
		coffee	Black tea	Red wine
AI	1	1.13±0.4	0.62±0.3	1.12±0.9
	7	1.76±1.1	1.22±0.4	2.42±1.7
	28	1.46±0.8	1.44±0.5	7.5±4
	90	1.1±0.5	1.53±0.3	1.66±0.8
	180	1.5±0.4	0.88±0.5	3.23±2.8
	t-test	0.032	<0.001	0.015
	After polishing	1.13±0.4	1.62±0.7	1.12±0.9
CT	1	1.57±1.3	1.96±4.1	2.19±4
	7	2.47±1.6	2.46±2.5	2.88±3.4
	28	1.48±0.9	1.31±0.8	2.14±3.7
	90	1.48±1.1	1.2±0.6	2.45±3.6
	180	1.71±1.7	1.04±0.9	2.17±4.1
	t-test	0.068	0.004	<0.001
	After polishing	2.03±1.4	1.5±1.1	2.7±4.2
UF	1	1.61±1.1	0.94±0.1	1.62±0.4
	7	2.04±1	0.7±0.4	1.33±0.6
	28	2.59±1.1	1.36±0.2	9.92±6.4
	90	2.82±1.1	0.68±0.1	9.25±11.4
	180	3.36±1.5	2.48±0.4	11.76±13
	t-test	0.003	0.001	0.124
	After polishing	2.02±0.7	2.14±0.4	6.37±4.1
GD	1	4.6±4.9	1.19±0.7	5.29±3.9
	7	7.78±3.9	1.88±0.9	11.01±0.9
	28	8.92±3.7	4.64±2	17.14±7
	90	9.72±5.3	2.52±1.6	18.26±6.1
	180	12.68±5.3	3.27±2	22.29±6.1
	t-test	<0.001	0.007	<0.001
	After polishing	7.13±3.5	0.96±0.4	11.53±4
CM	1	3.21±2.2	1.25±0.7	4.07±2
	7	4.92±3.1	1.92±0.9	9.53±3.6
	28	5.36±3.3	3.15±2.3	16.38±3.6
	90	5.76±4.5	5.3±5.6	19.32±5
	180	7.33±3.7	5.1±5.3	22.87±5.7
	t-test	0.018	0.804	<0.001
	After polishing	5.82±4	4.98±6	5.82±1.84
IE	1	1.1±0.2	0.98±0.1	1.17±0.1
	7	1.37±0.1	1.45±0.1	1.84±0.2
	28	0.76±0.1	0.47±0.1	6±3.2
	90	2.73±0.3	2.6±0.2	5.46±2.2
	180	0.71±0.2	0.86±0.1	2.14±0.9
	t-test	0.026	<0.001	0.012
	After polishing	1.24±0.6	2.08±0.4	1.1±0.2
CG	1	0.67±0.6	0.83±0.5	1.02±0.6
	7	1.6±1.1	0.97±0.7	1.58±1
	28	1.87±1.1	0.77±0.1	3.26±2.5
	90	2.16±1.6	2.74±0.9	2.02±1
	180	2.52±2.1	2.83±1	1.69±0.9
	t-test	<0.001	<0.001	0.571
	After polishing	2.26±2.1	2.77±0.9	1.84±1.3

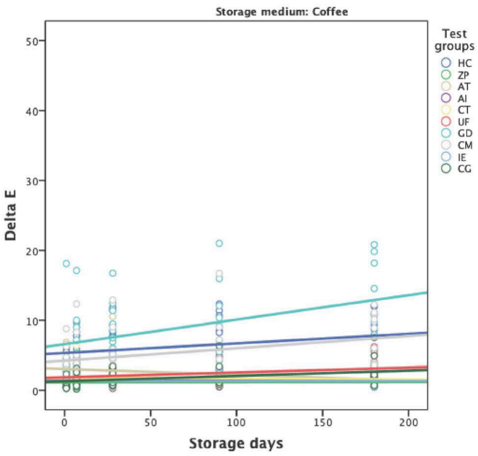

Fig. 1 Discoloration (ΔE) after coffee storage for each tested group at each aging level.

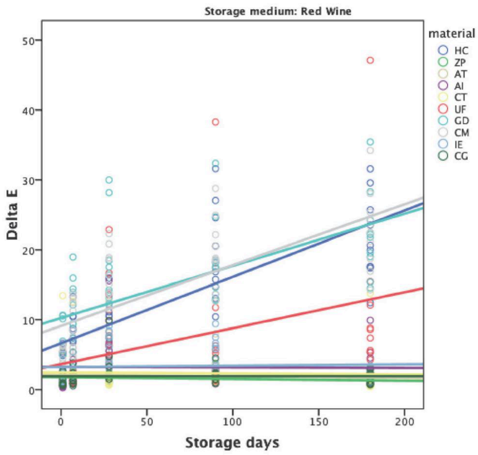

Fig. 3 Discoloration (ΔE) after red wine storage for each tested group at each aging level.

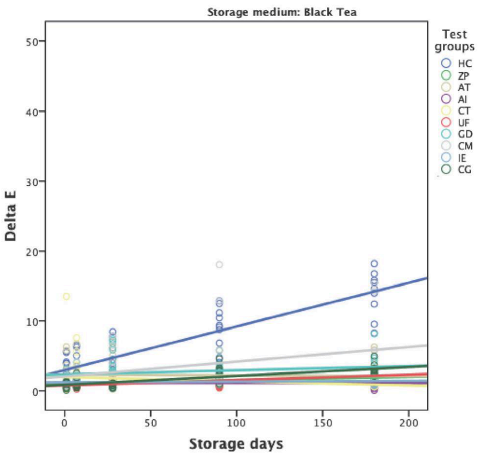

Fig. 2 Discoloration (ΔE) after black tea storage for each tested group at each aging level.

resin HC and manually polymerized resin CM presented higher increase in ΔE than the control group ($p \leq 0.047$). For the CAD/CAM resins AT, AI and CT, and for the manually polymerized PMMA-based resin IE less increase in ΔE were observed ($p \leq 0.005$) (Table 2, Fig. 2).

Regarding to the red wine storage, CAD/CAM resin composite HC and two manually polymerized resin composites GD and CM showed significantly higher ΔE than the control group at baseline ($p \leq 0.002$). These groups together with the manually polymerized PMMA-based resin UF showed higher increase of ΔE than the control group ($p<0.001$) (Table 2, Fig. 3).

After polishing using a prophylaxis paste to remove the discoloration ΔE of all tested groups presented decreased ΔE less than 3.3 in all media. Only, the composite-based materials GD, CM and HC showed higher discoloration about 3.3 ΔE in all media after polishing.

DISCUSSION

Resins for temporary FDPs and the tested glass-ceramic underwent color change when exposed to various storage media. According to the results of this study, overall in all storage media, the discoloration of the manually polymerized composites GD and CM was significantly higher compared to manually polymerized PMMA-based resins, industrially polymerized CAD/CAM blocks and glass-ceramic. Only one composite-based CAD/CAM resin, HC showed significantly higher discoloration than the glass-ceramic. ΔE of the remaining CAD/CAM resins was not significantly different compared to glass-ceramic. Therefore, both hypotheses of this study that CAD/CAM resins show similar discolorations compared to glass-ceramic and lower discoloration compared to manually polymerized resins are rejected. This study showed that the composites showed higher discoloration compared to PMMA-based resins. Other studies reported that the resin matrix used in the composite-based materials have an important impact on discoloration[20,24,34,35]. UDMA seems to be more color-resistant than Bis-GMA because of its low water absorption and solubility characteristics[36]. Discoloration of Bis-GMA monomer is attributed to the

-OH groups in this monomer that yields to more water sorption. Water uptake in Bis-GMA-based resins was shown to increase from 3 to 6% as the proportion of TEGDMA increased from 0 to 1%[35]. In this study, the manually polymerized composites were based on UDMA, and HC CAD/CAM resin was based on Bis-GMA and UDMA. This can be the reason why HC specimens stored in black tea showed after polishing higher discoloration than both UDMA-based resins.

Considering baseline measurements, the polymerization type of the resins had no significant impact on the discoloration. The storage duration in all media of all tested groups had a significant impact on the color stability. The composites showed higher increase in discoloration in respect to the storage duration more than the PMMA-based ones. Several studies indicated that some PMMA-based resins tend to discolor less than other temporaries, including dimethyl methacrylate (composites)[15,25,31,32]. Most dimethacrylates are more polar than the mono methacrylate PMMA and therefore have a greater affinity towards water and other polar liquids[33]. However, other studies have also demonstrated that there are resin composite materials presenting similar color stability[27,32].

The composite-based CAD/CAM block, HC probably polymerized insufficiently. Unfortunately, polymerization process details were not available from the manufacturer for this material. This CAD/CAM block showed redress color differences at several layers that were already visually evident. The discoloration with this material can be explained by the fact that polymerization parameters (temperature, time, press) of those blocks were not satisfactory that yielded to absorption of the storage media. Although HC consists of Bis-GMA and UDMA the percentages of these methacrylate monomers could have affected the results. In return, all other CAD/CAM blocks showed visually homogeneous structure. This study tested the discoloration for two different composite-based CAD/CAM blocks. For the other composite-based CAD/CAM block, CT showed comparable color stability with the glass-ceramic and with the other PMMA-based CAD/CAM resins.

In the present study, the discoloration of tested resins was dependent on storage duration and storage media. Similar observations were made in another *in-vitro* study for manually polymerized resins after 180 days, and the discoloration increased in ascending order with the black tea, coffee and red wine[37]. In other previous studies red wine was reported to produce the most severe discoloration in temporary resins, followed by coffee and tea[38,39]. In this study ΔE values were equal to or greater than 3.3 that considered to be clinically perceptible, based on previous reports[16,17]. After polishing, the ΔE values for black tea, coffee, and red wine decreased to below 3.3 ΔE and were therefore clinically acceptable, except for the manually polymerized composites GD, CM and the CAD/CAM composite HC.

The surface smoothness and roughness have direct impact to the susceptibility to extrinsic staining. In this study all specimens were polished in a standardized device for 4.5 min and for this reason, the measured color stability between the tested groups could be considered comparable.

Based on the findings, the CAD/CAM resins (except HC) showed comparable results with glass-ceramic. However, discoloration is only one variable that must be considered when choosing a material for long-term reconstructions. Discoloration is perhaps of great importance to patients and clinicians when working in the esthetic zone. Further studies should test other factors such as mechanical stability, wear and bond strength to cements. From the clinical point of view, in contrast to common clinical opinions, PMMA-based CAD/CAM resins tested showed similar discoloration values compared to glass-ceramic ones. This CAD/CAM resins could be alternative materials to glass-ceramic for FDP constructions at least for long-term provisionals. However, clinical longevity of these materials is not known to date. When CAD/CAM resins could replace glass-ceramics from optical and mechanical perspectives, they could be clinically utilized. Further clinical studies should be also considering antagonist enamel or restoration material wear against glass-ceramic *versus* CAD/CAM resins.

CONCLUSIONS

Within the limitations of this *in-vitro* study, the following conclusions can be drawn:

1. Four of the five tested CAD/CAM resins exhibited similar color stability compared to control group, glass-ceramic.
2. PMMA-based industrially and manually polymerized resins showed similar color stability.
3. Composite-based resins presented higher discoloration than the PMMA-based ones, except CT.
4. After polishing, the discoloration of all materials stored in black tea, coffee, and red wine decreased for PMMA-based materials.

ACKNOWLEDGMENTS

The authors would like to thank Merz Dental, Wieland+Dental, GC Europe, Ivoclar Vivadent and Vita Zahnfabrik for their support with the materials.

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2.3. Originalarbeit: Stawarczyk B, Özcan M, Trottmann A, Schmutz F, Roos M, Hämmerle CHF. Two-body wear rate of CAD/CAM resin blocks and their enamel antagonists. J Prosthet Dent 2013;106(5):325-332 .

Zusammenfassung

Ziel: Diese Studie testet und vergleicht die Abrasionsbeständigkeit von CAD/CAM-Kunststoffen, manuell polymerisierten Kunststoffen und Glaskeramik.

Material und Methode: Es wurden Prüfkörper (N=42, n=6 pro Gruppe) aus 5 verschiedenen CAD/CAM-Kunststoffen i) ZENO PMMA (ZP) ii) artBloc Temp (AT) iii) Telio CAD (TC) iv) Blanc High-class (HC) v) CAD-Temp (CT), einem konventionellen Kunststoff vi) Integral esthetic press (negative Kontrollgruppe, IEP) und einer Glaskeramik vii) VITA Mark II (positive Kontrollgruppe, VM2) hergestellt. Die zu testenden Materialien wurden in einer Kaumaschine (49 N, 1.67 Hz, 5/50°C) gealtert. Als Antagonist wurde ein mesio-bukkaler Höcker von einem menschlichen Zahn verwendet. Die Materialverluste wurden zuerst vor der Alterung (Baseline) bestimmt, dann nach 120.000, 240.000, 640.000 und nach 1.200.000 Kauzyklen. Die Messungen der Materialverluste fanden mittels 3DS-Profilometer statt. Alle erzielten Daten wurden statistisch mittels gemischten Modelle ausgewertet ($p<0.05$).

Ergebnisse: Der konventionelle Kunststoff zeigte die signifikant höchsten Materialverluste ($p<0.001$) im Vergleich zu allen anderen getesteten Gruppen. Glaskeramik dagegen wies signifikant geringere Materialverluste ($p<0.001$) auf als ZP, AT, HC, CT und IES. Der CAD/CAM-Kunststoff TC lag in einem Wertebereich mit Glaskeramik. An den Zahnschmelzantagonisten wurden in der Gruppe der Glaskeramik die höchsten Materialverluste beobachtet ($p<0.001$). Alle Kunststoffe bewirken sehr geringe Materialverluste am Zahnschmelz und lagen alle in einem Wertebereich. Des Weiteren wurden in der Glaskeramik-Gruppe nach der

Kausimulation bei 50% der Prüfkörper kleine Risse an den Schmelzantagonisten beobachtet.

Schlussfolgerung: Die in dieser Studie geprüften CAD/CAM-Kunststoffe zeigten höhere Abrasionsbeständigkeiten auf als ein konventioneller Kunststoff. Nur ein CAD/CAM-Kunststoff (TC) erzielte eine vergleichbare Abrasionsbeständigkeit zu Glaskeramik. Alle anderen getesteten Kunststoffe zeigten signifikant niedrigere Abrasionsbeständigkeiten als die Glaskeramik. Nur bei Glaskeramik wurden nach der Kausimulation bei 50% der Schmelzantagonisten Risse beobachtet, während bei den Kunststoffen alle Schmelzantagonisten intakt blieben.

Klinische Relevanz: Unter dem Aspekt der Abrasionsbeständigkeit ist es möglich, dass nur einer der getesteten CAD/CAM-Kunststoffe (TelioCAD) zukünftig zu einer Alternative zu Glaskeramik-Rekonstruktionen werden könnte.

Two-body wear rate of CAD/CAM resin blocks and their enamel antagonists

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Statement of problem. Computer-aided design and computer-aided manufacturing (CAD/CAM) resins exhibit good mechanical properties and can be used as long-term restorations. The wear rate of such resins and their enamel antagonists is unknown.

Purpose. The purpose of this study was to test and compare the 2-body wear rate of CAD/CAM resin blocks.

Material and methods. Wear specimens (N=42, n=6) were made from 5 CAD/CAM resins: ZENO PMMA (ZP), artBloc Temp (AT), Telio CAD (TC), Blanc High-class (HC), CAD-Temp (CT); 1 manually polymerized resin: Integral esthetic press (negative control group, IEP); and 1 glass-ceramic: VITA Mark II (positive control group, VM2). The specimens for the wear resistance were aged in a thermomechanical loading machine (49 N, 1.67 Hz, 5/50°C) with human enamel antagonists. The material loss of all specimens before, during, and after aging was evaluated with a 3DS profilometer. The measured material loss data of all tested groups were statistically evaluated with linear mixed model analysis (α=.05).

Results. Manually polymerized resin showed significantly higher material wear (*P*<.001) than all other tested groups. Glass-ceramic showed significantly lower wear values (*P*<.001) than CAD/CAM resins ZP, AT, HC, CT, and IES. CAD/CAM resin TC was not significantly different from the positive control group. Glass-ceramic showed the highest enamel wear values (*P*<.001) of all tested resins. No differences were found in the enamel wear among all resins. The glass-ceramic group showed damage in the form of cracks on the worn enamel surface in 50% of specimens.

Conclusions. CAD/CAM resins showed lower wear rates than those conventionally polymerized. Only one CAD/CAM resin, TC, presented material wear values comparable with glass-ceramic. The tested glass-ceramic developed cracks in the enamel antagonist and showed the highest enamel wear values of all other tested groups. (J Prosthet Dent 2013;109:325-332)

Clinical Implications

CAD/CAM resins with lower wear than conventionally polymerized resins may be an appropriate choice for long-term use because they showed lower wear on enamel antagonists than glass-ceramic.

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Computer-aided design and computer-aided manufacturing (CAD/CAM) technology allows milling of different materials for dental applications. As an alternative to ceramics, CAD/CAM polymers have been recently introduced for dental restorations, which can be processed more rapidly and at a lower cost.[1] The resin CAD/CAM blocks are polymerized at high temperature and pressure under controlled conditions, resulting in consistent chemical and mechanical properties and higher flexural resistance than manually polymerized blocks.[1-4] In general, because manually polymerized resins show lower fracture resistance, they are only indicated for interim fixed dental prostheses (FDPs).[1-3] After 3 months of water storage at 37°C and 5000 thermal cycles, CAD/CAM resin 3-unit FDPs showed significantly higher fracture load than those manually polymerized.[1] Another study tested the fracture load of 3-unit polymeric FDPs after 1.2 million masticatory cycles and observed higher mean values which were unaffected by aging compared to manually polymerized resins and glass-ceramic FDPs.[4] Therefore, polymeric CAD/CAM resins can be considered for long-term restorations instead of glass-ceramics for some patients. Furthermore, it was reported that polymeric CAD/CAM resins exhibited similar color stability to glass-ceramics.[5] Their mechanical properties, such as flexural strength are comparable to glass-ceramics,[6-7] but the hardness values of glass-ceramics[8] are higher than those of resins.[7] An advantage of all resin-based materials is their plastic deformability, which could prevent the spontaneous fracture of the restoration.

One of the important properties of dental materials is their wear resistance. Wear rate is defined as the loss of restorative material and/or its antagonist. The wear results because of mechanical contact in a solid or liquid body or the impact of chemical or mechanical reactions.[2] The physical properties of enamel,[9,10] parafunctional habits, eating habits, and the antagonist material have been reported to influence clinical wear.[10-17] The authors identified no information to date on the wear of polymeric CAD/CAM resins.

In vitro wear tests have been performed using different devices such as the Academisch Centrum Tandheelkunde Amsterdam (ACTA), Zurich, Alabama, Freiburg, Minnesota, Oregon Health & Science University (OHSU), or Newcastle wear simulators.[13] These test methods differ in the design, antagonist material, test medium, force application, and mobility of specimens.[13,18,19] The Zurich wear test method used human enamel antagonists, possibly making the test more clinically relevant.[13]

The objective of this study was to determine the 2-body wear rate of industrially polymerized CAD/CAM resins and compare this to manually polymerized resin and glass-ceramic. The study tested the null hypotheses that 1) the wear of CAD/CAM resins would be similar to manually polymerized resin, 2) the wear of CAD/CAM resins would be similar to glass-ceramic, and 3) the wear of antagonists of all tested groups would be similar.

MATERIAL AND METHODS

This study investigated the 2-body wear of 5 CAD/CAM resins: ZENO PMMA (ZP), artBloc Temp (AT), Telio CAD (TC), Blanc High-class (HC), CAD-Temp, 1 manually polymerized resin: Integral esthetic press (negative control group, IEP), 1 glass-ceramic VITA MARK II (positive control group, VM2), and their enamel antagonists by using the Zurich wear simulation (ISO/TS 14569-2).[13] The experimental groups are listed in Table I. For wear resistance testing, each test group included 6 specimens. The sample size was based on similar previous studies, which showed significant differences from a similar sample size.[20,21] No a priori power analysis was performed.

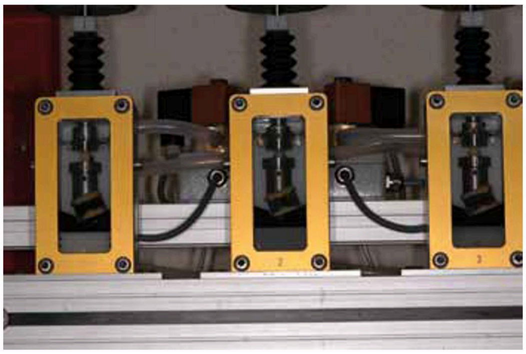
All CAD/CAM resins and glass-ceramic blocks were cut to a thickness of 2 mm with a low-speed diamond saw (Well 3241; Well Diamond Wire Saws Inc, Mannheim, Germany). The specimens were embedded in the center of circular stainless steel molds (inside diameter: 15 mm) with an autopolymerizing acrylic resin (Dura-Lay; Reliance Dental Mfg. Co, Worth, Ill). The manually polymerized IEP resin was directly poured into a stainless steel mold and polymerized according to the manufacturer's instruction in a pressure pot (30 minutes, 45 minutes, 0.25 MPa, Ivoclar Vivadent, Schaan, Liechtenstein). Subsequently, all specimens were polished with SiC paper P400, P1200, and P2400 (Labo-Pol-21; Struers, Ballerup, Denmark).

The specimens were aged in a custom-made mastication simulator (University of Zurich). The simulator was computer-controlled, exerting a maximum occlusal load of 49 N at 1.67 Hz. Thermal stresses varied between 5°C to 50°C every 120 seconds. The mesiobuccal cusps of maxillary human molars fixed in amalgam (Dispersalloy; Dentsply, Konstanz, Germany) were used as the antagonists. The tips of the cusps were adjusted to a spherical shape. The track of the enamel across the specimen surface was 2 mm. Figure 1 demonstrates the fixed specimens in the mastication simulator. The abraded surfaces were loaded intermittently. The protocol used for the mastication simulation was similar to previous studies.[20,21] The vertical material loss (µm) from the specimens and their enamel antagonists was analyzed with a custom made 3DS profilometer (University of Zurich). Measurements were made before aging (initial) and after 120 000, 240 000, 640 000, and 1 200 000 masticatory cycles.[13] The profiles with congruent points were overlapped, and the initial measurements were subtracted from later measurements. Subsequently, the material loss (µm) from the specimens and their enamel antagonists was calculated with the 3DS software (University of Zurich).

Additionally the specimens were

Table I. Test groups, abbreviations, brands, batch numbers, manufacturers, and composition of tested materials

Test Group	Abbreviation	Batch Number	Manufacturer	Composition
ZENO PMMA	ZP	0483	Wieland Dental + Technik, Pforzheim, Germany	PMMA-based
artBlock Temp	AT	13708	Merz Dental, Lütjenburg, Germany	PMMA, OMP=organic modified polymer network
Telio CAD	TC	MM1068	Ivoclar Vivadent, Schaan, Liechtenstein	99.5% PMMA Polymer
Blanc High-class	HC	2007000908	Creamed, Marburg, Germany	BODMA, Bis-GMA, UDMA, Strontium aluminum borosilicate glass 70.1%, nanofilled
CAD-Temp	CT	19180	Vita Zahnfabrik, Bad Säckingen, Germany	Acrylic polymer with 14% microfiller. MRP=microfilled reinforced polyacrylate
Integral esthetic press	IEP	1/4106 55007	Merz Dental	MMA, dimethacrylate, barbuturic acid catalyst system, PMMA, organic and inorganic pigments
Vita Mark II	VM2	16341	Vita Zahnfabrik	SiO-based glass-ceramic



1 Specimens fixed in mastication simulator.

analyzed with scanning electron microscopy (SEM) (Carl Zeiss Supra 50 VP FESEM; Carl Zeiss, Oberkochen, Germany) after the wear tests.

Descriptive statistics for all tested groups in each aging time were calculated. Linear mixed models for 2 different baselines (positive and negative control group) were applied to investigate the influence of the number of masticatory cycles, the restorative materials/enamel, and the interaction between them (Table II). The measured material loss data were analyzed with the statistical software (SPSS, v19; SPSS Inc, Chicago, Ill). The results of statistical analyses with P-values less than .05 were interpreted as statistically significant.

RESULTS

The means and standard deviations of the wear results of the materials and their enamel antagonists are presented in Figure 2. In general, the material ($P<.001$) and the number of masticatory cycles ($P<.01$) had a significant effect on the wear (Table II).

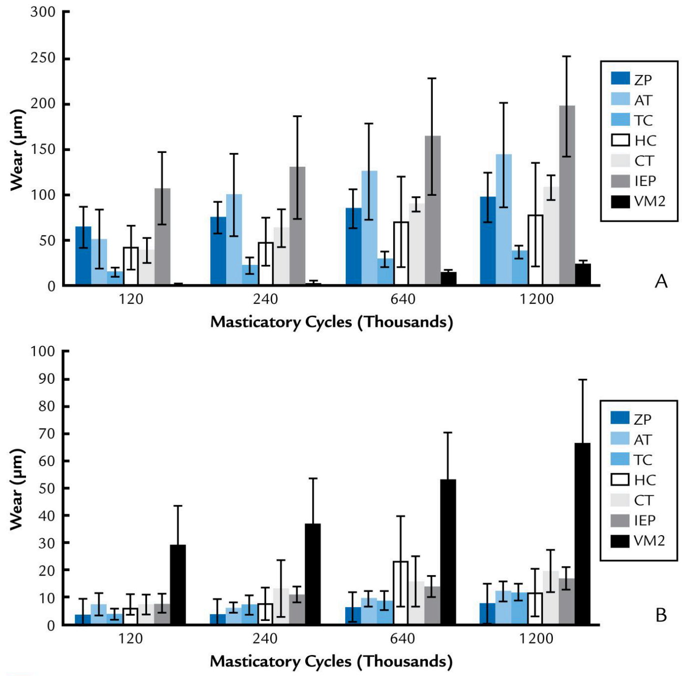
Material wear

The negative control group, IEP, showed significantly higher material wear ($P<.001$) than all CAD/CAM resins and the positive control group, VM2. Depending on masticatory cycles, the increase in the wear values was higher for the negative control group than for the CAD/CAM resins ZP, TC, HC, and the positive control group (Table II, Fig. 3, 5).

The positive control group, VM2, showed significantly lower wear values ($P<.001$) than the CAD/CAM resins ZP,

TABLE II. Estimates of regression coefficients for wear of restorative materials with positive (VM2) and negative group (IEP) as baseline (linear mixed model analysis)

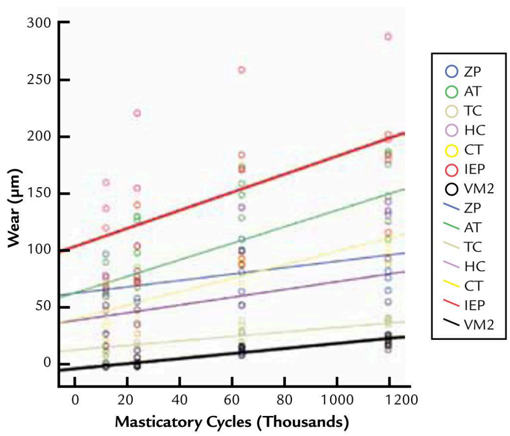
Parameter	With positive control group as baseline (VM2)			With negative control group as baseline (IEP)		
	Standard Error	P	95% CI	Standard Error	P	95% CI
Constant term	-1.9 (12.7)	.881	(-27.3;23.6)	105.5 (12.7)	<.001	(80.0;131.0)
ZP	66.4 (18.0)	.001	(30.3;102.4)	-41.0 (18.0)	.026	(-77.0;-5.1)
AT	66.6 (18.0)	<.001	(30.5;102.6)	-40.8 (18.0)	.027	(-76.8;-4.9)
TC	16.6 (18.0)	.359	(-19.3;52.7)	-90.8 (18.0)	<.001	(-126.7;-54.8)
HC	42.3 (18.0)	.022	(6.3;78.4)	-65.1 (18.0)	.001	(-101.0;-29.1)
CT	43.9 (18.0)	.018	(7.9;79.9)	-63.5 (18.0)	.001	(-99.4;-27.6)
IEP	107.4 (18.0)	<.001	(71.4;143.4)	0 (0)	-	-
VM2	0 (0)	-	-	-107.4 (18.0)	<.001	(-143.3;-71.5)
Masticatory cycles (MC)	2.2E-5 (8.7E-6)	.012	(4.9E-6;4.0E-5)	7.9E-5 (8.7)	<.001	(6.2E-5;9.7E-5)
ZP × MC	5.9E-6 (1.2E-5)	.635	(-1.8E-5;3.1E-5)	-5.1E-5 (1.2E-5)	<.001	(-7.5E-5;-2.7E-5)
AT × MC	5.1E-5 (1.2E-5)	<.001	(2.6E-5;7.5E-5)	-6.7E-6 (1.2E-5)	.588	(-3.1E-5;1.8E-5)
TC × MC	-2.7E-6 (1.2E-5)	.830	(-2.7E-5;2.2E-5)	-6.0E-5 (1.2E-5)	<.001	(-8.4E-5;-3.6E-5)
HC × MC	1.2E-5 (1.2E-5)	.337	(-1.2E-5;3.7E-5)	-4.5E-5 (1.2E-5)	<.001	(-6.9E-5;-2.1E-5)
CT × MC	3.7E-5 (1.2E-5)	.003	(1.2E-5;6.2E-5)	-2.0E-5 (1.2E-5)	.105	(-4.4E-5;4.3E-5)
IEP × MC	5.7E-5 (1.2E-5)	<.001	(3.2E-5;8.2E-5)	0 (0)	-	-
VM2 × MC	0 (0)	-	-	-5.7E-5 (1.2E-5)	<.001	(-8.1E-5;-3.3E-5)



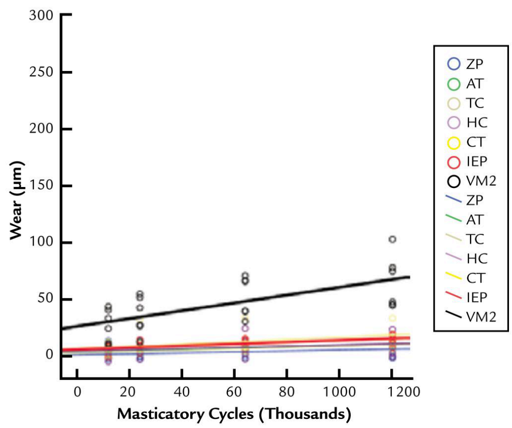
2 Wear (µm) of all tested A, Restorative materials. B, Enamel antagonists after 120 000, 240 000, 640 000, and 1 200 000 masticatory cycles.

Table III. Estimates of regression coefficients for wear of enamel antagonist with positive (VM2) and negative group (IEP) as baseline (linear mixed model analysis)

Parameter	With positive control group as baseline (VM2) Standard Error	*P*	95% CI	With negative control group as baseline (IEP) Standard Error	*P*	95% CI
Constant term	27.8 (3.3)	<.001	(21.1;34.4)	7.5 (3.3)	.026	(0.9;14.2)
ZP	-25.0 (4.6)	<.001	(-34.2;-15.7)	-4.8 (4.6)	.311	(-14.0;4.6)
AT	-22.0 (4.6)	<.001	(-31.4;-12.8)	-1.8 (4.6)	.697	(-11.1;7.6)
TC	-23.7 (4.6)	<.001	(-33.1;-14.5)	-3.5 (4.6)	.45	(-12.8;5.8)
HC	-21.7 (4.6)	<.001	(-31.0;-12.4)	-1.5 (4.6)	.753	(-10.7;7.9)
CT	-19.4 (4.6)	<.001	(-28.7;-10.1)	0.8 (4.6)	.867	(-8.5;10.2)
IEP	-20.2 (4.6)	<.001	(-29.5;-10.9)	0 (0)	-	-
VM2	0 (0)	-	-	20.2 (4.6)	<.001	(10.8;29.6)
Masticatory cycles (MC)	3.4E-5 (1.9E-6)	<.001	(3.0E-5;3.8E-5)	8.0 (1.9)	<.001	(4.4E-6;1.2E-5)
ZP x MC	-3.0 (2.8E-6)	<.001	(-3.5E-5;-2.5E-5)	-3.7E-6 (2.8E-6)	.173	(-9.2E-6;1.7E-6)
AT x MC	-2.9 (2.8E-6)	<.001	(-3.4E-5;-2.4E-5)	-2.6E-6 (2.8E-6)	.347	(-8.0E-6;2.9E-6)
TCx MC	-2.8 (2.8E-6)	<.001	(-3.3E-5;-2.3E-5)	-1.5E-6 (2.8E-6)	.599	(-6.9E-6;4.0E-6)
HCx MC	-2.9 (2.8E-6)	<.001	(-3.3E-5;-2.4E-5)	-2.6E-6 (2.8E-6)	.355	(-8.0E-6;2.9E-6)
CTx MC	-2.4 (2.8E-6)	<.001	(-2.8E-5;-1.9E-5)	1.9E-6 (2.8E-6)	.489	(-3.5E-6;7.4E-6)
IEPx MC	-2.6 (2.8E-6)	<.001	(-3.1E-5;-2.1E-5)	0 (0)	-	-
VM2x MC	0(0)	-	-	2.6E-5 (2.8E-6)	<.001	(2.0E-5;3.2E-5



3 Linear mixed model diagram of restorative materials wear.



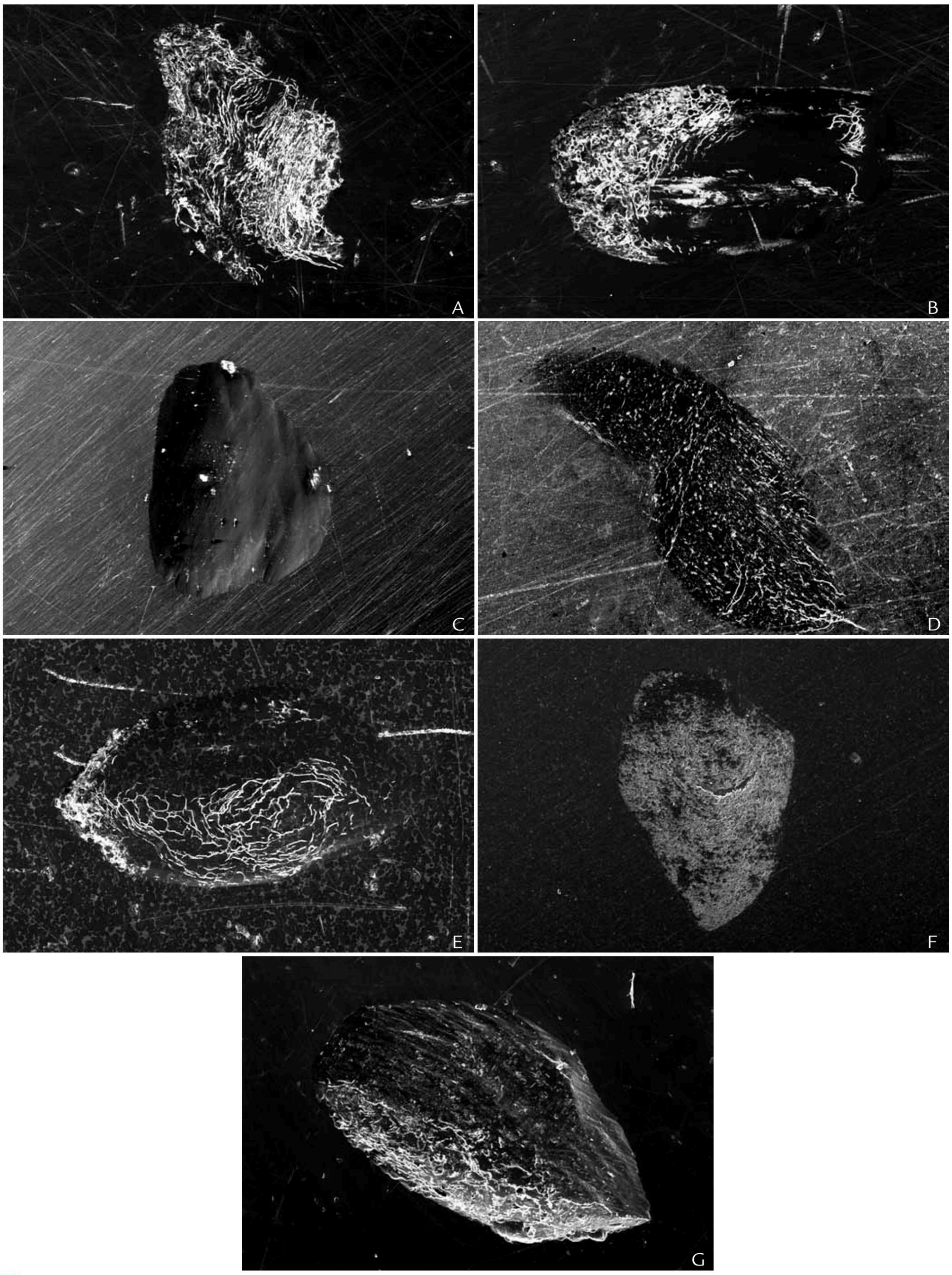
4 Linear mixed model diagram of enamel antagonist wear.

AT, HC, CT, and the negative control group, IES. The CAD/CAM resin TC did not significantly differ from the positive control group. Depending on the aging time, the increase in the wear values was lower for the positive control group than for the CAD/CAM resins AT, CT and the negative control group IEP (Table II, Figs. 3, 5).

Antagonist enamel wear

The positive control group, VM2 glass-ceramic, showed the highest enamel wear values (*P*<.001) with the highest increase in material lost (*P*<.001) compared to all CAD/CAM resins and the negative control group, IEP. No differences were found in the enamel wear between all resins (Table III, Fig. 4).

An evaluation of the enamel antagonists with SEM showed damage in the form of cracks on the worn enamel surfaces of the glass-ceramic group. For both manually polymerized and CAD/CAM resins, no damage to the enamel antagonists was observed.



5 SEM images (magnification ×250) of abraded restorative materials after 1 200 000 masticatory cycles. A, Group ZP. B, Group AT. C, Group TC. D, Group HC. E, Group CT. F, Group IE. G, Group VM2 (control group).

Discussion

All industrially polymerized CAD/CAM resins showed lower vertical material loss (wear) than manually polymerized resins. Therefore, the first null hypothesis of this study was rejected.

The second null hypothesis tested was whether the wear of CAD/CAM resins would be similar to glass-ceramic. Four CAD/CAM resins showed higher material wear values compared to glass-ceramic. Only one CAD/CAM resin, TC, showed similar wear to glass-ceramic. Therefore, this hypothesis was partially rejected. TC is a polymethylmethacrylate (PMMA) resin without organic or inorganic filler. In general, no correlation was found between the tested CAD/CAM resins and their composition. Therefore, it is possible that the press and polymerization parameters of the CAD/CAM resins have a significant impact of the wear rate.

The third null hypothesis was to test whether the wear of the antagonists of all tested groups would be similar. The glass-ceramic showed significantly higher wear on the antagonists than on the resins. Therefore, the third null hypothesis was rejected. The hardness values of glass-ceramic compared to resins were higher. The hardness and surface texture of the restoration surface are the most important criteria for lower wear rate. For higher mechanical properties, glass-ceramic is reinforced with further ceramic particles. During the thermomechanical loading process the particles may be pulled out. Consequently, with the increase in the masticatory cycles during the aging process, the wear rate of the glass-ceramic increased. Therefore, the material surface was rough and increased the abrasion of the enamel antagonists. Additionally, the enamel antagonists showed damage in the form of cracks on the worn enamel surfaces of the specimens in the glass-ceramic group. For the resin groups, no damage of the enamel antagonists was observed. During aging in the masticatory simulator, both surfaces (enamel antagonist and glass-ceramic/resin) were abraded by direct contact, and during the movement, the asperities must have been either fractured or deformed. If both surfaces are brittle, such as in the positive control group of enamel against glass-ceramic, fracture of the asperities does occur.

In all tested groups in this study, the wear standard deviation varied highly. The lack of homogeneity in the human enamel antagonists, in the thickness or geometry of the enamel layers, and in the storage conditions possibly affected the results.[14] The variations in the morphologies of the human tooth affect the wear rate.[13] However, the use of human enamel antagonists represents the clinical situation.

Little or no correlation was found between in vitro and in vivo studies.[14] This could be attributed to the magnitude and frequency of the force.[10,15-17] In this study, thermal cycling with water also contributed to the aging of the specimens.[14]

As the measurements for each specimen were made before aging and after 4 additional masticatory cycles, the predictor MC can be considered to be a dimensional variable rather than a factor with 5 levels as visualized in Figures 2 and 3. In such a case, the multiple regression methodology applies, and the estimated regression coefficients, along with their 95% CIs, for each of the materials in a regression model can be used to assess whether the materials differ. The baseline can be set to be the positive or alternatively the negative control group. As the tested specimens were used repeatedly for all MC and the measurements from each specimen were correlated, the longitudinal data were considered for statistical analysis. Consequently, the linear mixed models with random intercept, which were adjusted for the correlated data, were applied in order to investigate the influence of the number of chewing cycles.

A limitation of this study was the choice of the control groups. For the positive control group, glass-ceramic was used; all other tested materials were filled or unfilled polymeric resins. This study compared different classes of materials with different wear mechanisms. Glass-ceramic is a brittle material, whereas the resins are ductile. The idea for this study was to test the wear properties of different CAD/CAM resins with the expectation that, in the future, glass-ceramic restorations may be replaced with resins. However, the currently available CAD/CAM resins exhibit higher wear values than glass-ceramic. Additional work is needed to improve the wear properties of resins. Another limitation was the fact that no a priori power analysis was performed to determine sample size.

One study investigated and compared different two- and/or three-wear test devices such as ACTA Zurich (University of Zurich), Alabama (University of Alabama at Birmingham), MTS (Material Testing Systems), and OHSU for direct composite resins.[18] The measured wear resistance of the tested resin composites with the different wear test methods showed no comparable results as all methods follow different wear testing concepts. However, in vitro studies for wear resistance tests show little correlation with clinical data[19] but do present a comparative evaluation of different materials under standardized conditions.[10] The results of this study require clinical verification.

Conclusion

Within the limitations of this study, the following conclusions were drawn: CAD/CAM resins showed lower wear values than those manually polymerized. CAD/CAM resins showed higher wear values than glass-ceramic, with the exception of TC. Both manually polymerized and CAD/CAM resins showed lower enamel antagonist wear values than glass-ceramic. Although in the glass-ceramic group 50% of the specimens developed cracks in enamel, no such damage was observed in the resin groups.

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Acknowledgments
The authors thank Mrs Jacqueline Hofmann, Center of Dental Medicine, University of Zurich, for performing the scanning electron microscopy, and Wieland Dental + Technik, Merz Dental, Ivoclar Vivadent and Vita Zahnfabrik for material support.

3. Diskussion

In diesem Abschnitt werden die jeweiligen Untersuchungen einzeln diskutiert.

3.1. Bruchlasten von dreigliedrigen CAD/CAM Kunststoff-Brücken

Diese Studie hat gezeigt, dass eine Lagerung im künstlichen Speichel bei 37°C bis zu 6 Monaten keinen Einfluss auf die Bruchlastwerte von dreigliedrigen CAD/CAM-gefertigten Kunststoff-Brücken hat. Des Weiteren wurde beobachtet, dass die Alterung im Kausimulator bis 1.2 Mio. Kauzyklen ebenfalls keinen negativen Einfluss auf die Bruchlastwerte der CAD/CAM-Kunststoffe hat mit einer Ausnahme von ZENO PMMA. Im Gegensatz dazu wurde bei konventionellen Kunststoffen eine Abnahme der Bruchlast in Abhängigkeit der Lagerungszeit in künstlichem Speichel festgestellt. Ebenfalls zeigte bereits eine geringe Anzahl von Kauzyklen einen negativen Einfluss auf die Bruchlastwerte bei konventionellen Kunststoffen sowie auch bei der Glaskeramik. Vor diesem Hintergrund muss die erste Hypothese der Studie, dass die CAD/CAM-Kunststoffe nach den Alterungsprozessen vergleichbare Bruchlasten zu den konventionellen Kunststoffen aufweisen, abgelehnt werden. Die standardisierte industrielle Polymerisation der CAD/CAM-Kunststoffe unter optimalen Konditionen führt zur einen Verbesserung der physikalischen Eigenschaften und minimiert sogar das Risiko von Porosität innerhalb des Gefüges [13]. Das führt dazu, dass die CAD/CAM-gefertigten Kunststoffrekonstruktionen im Vergleich zu den konventionellen Kunststoffen stabiler werden. Im Gegensatz dazu können die mechanischen Eigenschaften von konventionell hergestellten Kunststoffbrücken durch viele Parameter beeinflusst werden wie z.B. durch die fehlerbehaftete manuelle Herstellung, dem Anmischverhältnis der Kunststoffkomponenten, die Polymerisationseinheit sowie die Dauer der Polymerisation.

In dieser Studie wurde Glaskeramik als Kontrollgruppe verwendet. Glaskeramik stellt das am häufigsten eingesetzte Restaurationsmaterial für ästhetische CAD/CAM-Einzelzahnrekonstruktionen wie Inlays, Onlays, Veneers und Kronen dar. Im Vergleich zu allen hier geprüften Kunststoffen wiesen Glaskeramik-Brücken in dieser Studie die kleinsten Bruchlastwerte auf. Folglich muss die zweite Hypothese dieser Studie, dass die CAD/CAM Kunststoff-Brücken höhere Bruchlastwerte zeigen als Glaskeramik-Brücken, bestätigt werden.

Bei dem konventionellen Kunststoff CronMix K für Direktprovisorien wurde nach einem Tag Speichellagerung bei 37°C eine Zunahme der Bruchlastwerte beobachtet. Vermutlich hat in dieser Zeit eine Nachpolymerisation stattgefunden, die zu einer Zunahme der Festigkeit geführt hat. Auch eine weitere Studie konnte eine Zunahme der Festigkeit von den Initialwerten zu den Werten, die nach 24 Stunden gemessen wurden, feststellen [14]. In dieser Studie wurde diese Steigerung der Bruchlast ebenfalls nach 120.000 Kauzyklen im Kausimulator beobachtet. *Burtscher* [15] beobachtete in seinen Untersuchungen, dass die freien Radikale bis zu 7 Tagen nach der Freisetzung aktiv sein können und nachpolymerisieren. Die Resultate der vorliegenden Studie bestätigen diese Beobachtungen, denn es wurde erst nach 7 Tagen Speichellagerung die Endfestigkeit der Brücken erreicht. Im Gegensatz dazu konnte dieses Phänomen bei den kausimulierten Brücken nicht beobachtet werden. Dort war die Endfestigkeit bereits nach einem Tag erreicht worden.

In der vorliegenden Studie wurde die Kausimulation als eine der Alterungsmöglichkeiten gewählt, weil sie für alle Prüfkörper eine standardisierte und reproduzierbare Belastung ausübt. Dazu wurde eine Kaumaschine mit zusätzlichen Thermolastwechsel von 5°C und 50°C verwendet. Diese Alterungsmethode ist in der dentalen Werkstoffkunde bewährt und hat sich etabliert um eine kliniknahe Situation zu simulieren [16,17]. Als Grundlage wird von der Tatsache ausgegangen, dass eine Kausimulation mit 50 N bei 1.2 Mio Kauzyklen umgerechnet einer etwa 5-jährigen klinischen Belastung und damit der Mundsituation des Patienten entspricht [18]. Diese Annahme wurde jedoch nicht systematisch mit verschiedenen Materialien überprüft und basiert auf einer Hochrechnung von klinischen Studien mit einer Beobachtungszeit von 4 Jahren mit Amalgamfüllungen und 6-monatiger Beobachtungszeit von Kompositfüllungen [18]. In beiden Fällen handelt es sich um Abrasionsbeständigkeiten der Füllungsmaterialien. Zusammenfassend ist festzustellen, dass für diese Umrechnungsfaktoren und vor allem für weitere Prüfmethoden, wie z.B. für die Bruchlastbestimmung von Brücken, noch weitere longitudinale Daten weiterer klinischer Studien sowie in-vitro-Studien notwendig sind. Deswegen muss an dieser Stelle betont werden, dass diese Umrechnung von 1.2 Kauzyklen in eine 5-jährige klinische Belastung nur ein Richtwert sein kann und nicht eins zu eins von in-vitro in in-vivo umgesetzt werden darf.

Die Alterung im Kausimulator sowie die Messung der Bruchlast hat auf „Stahlmodellen“ stattgefunden. Das Paradont wurde in der vorliegenden Studie mittels eines im Modell eingearbeiteten Silikonmaterials simuliert. Selbstverständlich hat die Wahl des Modellwerkstoffes einen signifikanten Einfluss auf die Bruchlastwerte. So wurde bereits in früheren Untersuchungen beobachtet, dass beweglich gelagerte Stümpfe signifikant tiefere Bruchlastwerte zeigten, als die starr gelagerten [2,19,20,22]. Des Weiteren wird darüber berichtet, dass der E-Modul des Modellwerkstoffes einen signifikanten Einfluss auf die Bruchlastwerte hatte [19,20]. Je höher der E-Modul des Modellwerkstoffes war, desto höher waren die gemessenen Bruchlastwerte [21]. Um der klinischen Situation sehr nah zu kommen, wäre es optimal, einen Modellwerkstoff zu wählen, der einen ähnlichen E-Modul wie die Zahnsubtanz aufweist [2,22].

Außerdem ist anzumerken, dass die in dieser Studie geprüften Brücken während der Bruchlastmessung nicht auf dem Modell zementiert waren. Dieser Aspekt sollte in zukünftigen Studien untersucht werden, denn durch die fehlende Zementierung kann ein zusätzliches Biegemoment der Brücke auf dem Modell entstehen, das zu einer Dämpfungswirkung führen könnte.

Das in dieser Studie verwendete Brücken-Design war zudem okklusal flach gestaltet und repräsentierte damit nicht die reale klinische Situation. Außerdem wurden diese Brücken nicht verblendet. Dies sind sicherlich mögliche Kritikpunkte dieser Studie. Dennoch ermöglichen die Resultate einen guten Vergleich zwischen den getesteten Gruppen, da die Brücken aller Gruppen formkongruent waren und identisch geprüft wurden. Daher können die Aussagen dieser Studie durchaus weiter verwendet werden. Nichtsdestotrotz sollten sich weitere Studien anschliessen, die die möglichen Schwächen dieser Studie berücksichtigen.

In der vorliegenden Studie wurde ein Verbinderquerschnitt von 7.36 mm^2 verwendet. Die Hersteller der CAD/CAM-Kunststoffe empfehlen jedoch wesentlich größere Verbinderquerschnitte. So werden für artBloc Temp 9 mm^2 und für CAD-Temp 12 mm^2 empfohlen. Klinisch gesehen kann eine zu grosse Verbinderquerschnittfläche das Parodontalgewebe gefährden. Dies war der Grund, dass in dieser Studie eine kleine Verbinderquerschnittfläche gewählt wurde. Es kann allerdings davon ausgegangen werden, dass eine größere Verbinderquerschnittfläche zu noch höheren Bruchlastwerten führen würde [23].

In Abhängigkeit von Messmethode, Geschlecht, Restaurationstyp, Ernährung und zahlreichen anderen Parametern wird die durchschnittliche klinische okklusale Kaukraft zwischen 12 und 90 N und die maximale Kaukraft im Seitenzahnbereich bei 909 N angegeben [24]. Die in dieser Studie geprüften CAD/CAM-Kunststoffbrücken wiesen Bruchlastwerte von 500 N und zeigten damit das Potential für klinische Applikationen ohne Beschränkungen eingesetzt werden zu können.

Fasbinder et al. [25] untersuchte in einer klinischen Studie CAD/CAM hergestellte Komposit-Inlays und beobachtet, dass nach 3 Jahren Beobachtungszeit sie eine signifikant bessere Farbstabilität aufwiesen als die ebenfalls untersuchten Glaskeramik-Inlays. *Lehmann et al.* [26] beobachteten demgegenüber bei einer Beobachtungszeit von 5 Jahren klinische Komplikationen wie eine unzureichende Abrasionsbeständigkeit und erhöhte Plaqueanlagerung von konventionellen Komposit-Kronen. Sie berichteten, dass konventionell gefertigte Komposit-Kronen durchaus als Langzeitpovisorien eingesetzt werden könnten, aufgrund der geringen Abrasionsbeständigkeit und hohen Plaqueanlagerung jedoch nicht für permanente Rekonstruktionen verwendet werden sollten. *Vanoorbeek et al.* [27] beobachtet in einer in-vivo-Studie mit einer Beobachtungszeit von 3 Jahren, dass CAD/CAM-gefertigte Komposit-Kronen geringere Erfolgsraten aufwiesen als CAD/CAM-gefertigte Glaskeramikkronen. Das Fazit dieser Studie war, dass aufgrund der schlechteren Ästhetik sowie der ungenügenden Abrasionsbeständigkeit Keramiken für metallfreie Rekonstruktionen vorgezogen werden sollten.

Da die meisten klinischen Studien konventionelle Kunststoffen im Vergleich zu Glaskeramik untersuchen, ist es zwingend notwendig, weitere in-vivo sowie auch in-vitro-Studien mit CAD/CAM-Kunststoffen durchzuführen.

Eindeutig ist, dass sich als ein Nachteil der Kunststoffe deren unzureichende Abrasionsbeständigkeit herausgestellt hat. In einem weiteren Abschnitt werden daher nachfolgend die Resultate von unserer Abrasionsbeständigkeitstudie vorgestellt und diskutiert.

3.2. Farbstabilität von CAD/CAM Kunststoffen

Die getesteten Kunststoffe sowie die Glaskeramik zeigten in allen drei Lagerungsflüssigkeiten wie Schwarztee, Kaffee und Rotwein Verfärbungen in Abhängigkeit von der Lagerungszeit. Gemäß der Resultate dieser Studie wurde in allen Lagerungsflüssigkeiten beobachtet, dass konventionelle Komposite signifikant höhere Verfärbungen aufwiesen als alle anderen hier geprüften Materialien. In Vergleich mit der Glaskeramik wurden nur bei einem CAD/CAM-Kunststoff, nämlich dem Komposit Blanc High-class, höhere Verfärbungsraten beobachtet. Alle anderen CAD/CAM-Kunststoffe lagen in einem Wertebereich vergleichbar mit der Glaskeramik. Deswegen müssen beide Arbeitshypothesen, sowohl dass die CAD/CAM-Kunststoffe vergleichbare Verfärbungsraten zu Glaskeramiken aufweisen, als auch dass sie farbstabiler als konventionelle Kunststoffe sind, abgelehnt werden.

Diese Studie hat gezeigt, dass grundsätzlich Komposite signifikant höhere Verfärbungsraten aufweisen als PMMA-basierte Kunststoffe. Andere Studien berichten, dass die Kunststoffmatrix der Komposite ein wichtiger Faktor für die Verfärbungsraten der Kunststoffe darstellt [40,44,54,55]. Aufgrund der geringeren Wasserabsorbtion und seiner Löslichkeitscharakteristik scheint das Monomer UDMA farbstabiler zu sein als Bis-GMA [56]. Bis-GMA Monomer enthält –OH Gruppen, die Wasser aufnehmen können und somit schneller verfärben. Die Wasseraufnahme von Bis-GMA-basierten Kunststoffen liegt zwischen 3-6%, während sich die von TEGDMA-basierten bei ca. 0-1% bewegt [55]. In dieser Untersuchung waren die konventionellen Komposite auf UDMA-Basis, während der CAD/CAM Komposite Blanc High-class aus Bis-GMA und UDMA bestand. Dies könnte der Grund dafür gewesen sein, dass das CAD/CAM-Komposit, welches im Schwarztee gelagert wurde, nach der Politur signifikant höhere Verfärbungen aufwies als die beiden konventionellen UDMA-basierten Komposite.

Anfangs wurden bei allen Kunststoffen ähnliche Verfärbungsraten beobachtet. Mit dem Anstieg der Lagerungszeit konnten allerdings Unterschiede zwischen den Kunststoffen beobachtet werden. So zeigten die Komposite, im Vergleich zu den PMMA-basierten Kunststoffen, eine höhere Verfärbungsrate in Anhängigkeit der Lagerungszeit. Weitere Studien zeigten ebenfalls, dass PMMA-basierte Provisorien weniger Verfärbungen aufweisen als provisorische Materialien, die wie Komposite, Dimethacrylate enthalten [35,45,51,52]. Die meisten Dimethacrylate sind mehr polar als die Monomethylmethacrylate PMMA. Deswegen haben sie eine höhere Wasseraffinität [53]. Dennoch gibt es auch Studien, die zeigten, dass es keinen Unterschied in Bezug auf die Farbstabilität zwischen Kompositen gibt [47,52].

Die hohe Verfärbungsrate von dem CAD/CAM-Komposit Blanc High-class ist vermutlich auf die ungenügende Polymerisation zurückzuführen. Zu diesem Punkt werden allerdings keine Angaben der Hersteller gemacht. Dieser CAD/CAM-Kunststoff zeigte einzelne Schichten im Gefüge, die stärker verfärbten als die restlichen Materialanteile. Es könnte vermutet werden, dass der Rohling in mehreren Schichten auspolymerisiert wurde und somit die einzelnen stärker verfärbten Schichten weniger auspolymerisiert waren, als der weniger verfärbte Anteil. Eine andere Erklärung könnte der Anteil von Bis-GMA in der Monomermatrix sein.

Die weiteren, in dieser Studie getesteten CAD/CAM Kunststoffe bestehen aus einer PMMA-basierten Matrix. Bei ZENO PMMA, artBloc Temp sowie artegral ImCrown handelt es sich um nicht gefüllte PMMA-Kunststoffe. CAD-Temp dagegen ist mit wenigen Gewichtsanteilen unter 10% gefüllt. Zwischen diesen PMMA-basierten Kunststoffen wurden keine Unterschiede in den Verfärbungsraten beobachtet. Die Farbstabilität dieser Kunststoffe war vergleichbar mit der Glaskeramik.

In dieser Studie wurde beobachtet, dass die Lagerungszeit sowie die Lagerungsflüssigkeit einen Einfluss auf die Höhe der Verfärbung hatte. Ähnliche Beobachtungen wurden in einer früheren in-vitro-Studie gemacht [57]. Dort wurden die Prüfkörper ebenfalls bis zu 180 Tagen im Schwarztee, Kaffee oder Rotwein gelagert. Mit der Zunahme der Lagerungszeit nahm die Verfärbungsrate in allen Flüssigkeiten zu [57]. Parallel zu unserer Studie wurden auch in anderen Studien die höchsten Verfärbungen im Rotwein, gefolgt von Kaffeeeinlagerung und die geringsten im Schwarztee gemessen [58,59]. In der vorliegenden Studie waren nach der Lagerungszeit von 180 Tagen alle ΔE-Werte gleich oder grösser als 3,3. Andere Studien berichten, dass ab einem ΔE-Wert von 3,3 eine sichtbare Verfärbung mit dem menschlichen Auge erfassbar ist [36,37]. Nach der Politur ist der ΔE-Wert bei allen Gruppen außer den konventionellen Kompositen sowie dem CAD/CAM-Komposit Blanc High-class jedoch unter den Wert 3,3 gesunken; somit waren die Verfärbungen klinisch nicht relevant.

Die Oberflächenbeschaffenheit und -rauhigkeit hat einen direkten Einfluss auf die Anfälligkeit der äußeren Verfärbung. In dieser Studie wurden alle Prüfkörper einheitlich für 4,5 Minuten maschinell poliert. Da die Politur bei allen Prüfkörpern einheitlich war, ist es durchaus möglich, die Verfärbungsraten zwischen den getesteten Materialien miteinander zu vergleichen.

Zusammenfassend kann anhand dieser Studie belegt werden, dass CAD/CAM-Kunststoffe, mit der Ausnahme von Blanc High-class, vergleichbare Farbbeständigkeiten wie die Glaskeramik aufweisen. Dennoch ist die Farbbeständigkeit nur ein Parameter von vielen, um die klinische Tragedauer der

Rekonstruktion zu bestimmen. Die Verfärbungsbeständigkeit hat sicherlich eine große Bedeutung im Frontzahnbereich sowie bei Patienten mit einem hohen ästhetischen Anspruch. Im Gegensatz zu den herkömmlichen klinischen Meinungen zeigen PMMA-basierte CAD/CAM-Kunststoffe mit der Glaskeramik vergleichbare Farbbeständigkeiten. Deswegen ist es durchaus möglich, dass CAD/CAM-Kunststoffe in Zukunft eine Alternative zu Glaskeramik als definitive Rekonstruktion werden. Dazu müssen vor allem noch weitere klinische Studien durchgeführt werden.

Die Studien zur mechanischen Stabilität und Abrasionsbeständigkeit von CAD/CAM-Kunststoffen werden im folgenden Abschnitt dieser Dissertation vorgestellt und diskutiert.

3.3. Abrasionsbeständigkeit von CAD/CAM Kunststoffen

In dieser Untersuchung zeigten alle CAD/CAM Kunststoffe signifikant höhere Abrasionsbeständigkeiten als konventionelle Kunststoffe. Somit konnte die erste Nullhypothese dieser Studie, dass CAD/CAM-Kunststoffe gleiche Abrasionsbeständigkeiten aufweisen wie die konventionellen Kunststoffe, abgelehnt werden. Die zweite Nullhypothese in dieser Studie testete, ob die CAD/CAM Kunststoffe vergleichbare Abrasionsbeständigkeiten wie die Glaskeramik haben. Vier der fünf getesteten CAD/CAM-Kunststoffe hatten signifikant höhere Materialverluste als die Glaskeramik nach der Kausimulation. Nur ein CAD/CAM-Kunststoff TelioCAD wies vergleichbare Materialverluste wie die Glaskeramik auf. So kann die zweite Nullhypothese nur teilweise bestätigt werden. Bei TelioCAD handelt es sich um einen ungefüllten PMMA-basierten Kunststoff. ArtBloc Temp, artegral ImCrown sowie auch ZENO PMMA sind ebenfalls PMMA-basierte Kunststoffe ohne eingearbeitete Füllstoffe. So konnte generell in dieser Studie keine Korrelation zwischen der Zusammensetzung der Materialien und deren Abrasionsbeständigkeit gefunden werden. Deswegen ist es möglich, dass hier andere Parameter eine entscheidende Rolle spielen wie z.B. die Press- sowie Polymerisationsart.

Die dritte Nullhypothese dieser Studie testete, ob die Materialverluste der Schmelzantagonisten bei allen Gruppen gleich hoch sind. Bei der Glaskeramik-Gruppe im Vergleich zu den Kunststoff-Gruppen wurden die höchsten Materialverluste bei dem Schmelzantagonisten beobachtet. Somit wurde die dritte Nullhypothese dieser Studie angelehnt. Der Schmelzmaterialverlust kann mit der Härte der Glaskeramik zusammenhängen, da Glaskeramik eine höhere Härte aufweist als Kunststoffe. Die Härte sowie die Oberflächenbeschaffenheit haben einen signifikanten Einfluss auf die Abrasionsbeständigkeit von Werkstoffen. Glaskeramiken werden mit weiteren Partikeln verstärkt, um höhere mechanische Eigenschaften, wie die Festigkeit und Bruchzähigkeit zu erreichen. Diese Partikel scheinen während der Kausimulation sich aus dem Gefüge zu lösen und bewirken eine rauhere Keramikoberfläche. Mit der Steigerung der Anzahl der Kauzyklen während des Alterungsprozesses nahmen die Materialverluste in der Glaskeramik zu, die Oberfläche wurde rauher und der Schmelzantagonist radierte konsequent immer mehr ab. Des Weiteren wurden in der Gruppe der Glaskeramik nach der Kausimulation kleine Risse im Schmelz beobachtet, während bei den Kunststoff-Gruppen alle Schmelzantagonisten intakt blieben. So abradierten während der Kausimulation nicht nur beide Flächen (Antagonist und Glaskeramik), sondern es kam zusätzlich durch den harten direkten Kontakt während des „Zubeissens“ im Kausimulator zu Frakturen der antagonistischen Schmelzoberfläche.

In dieser Studie wurde bei allen hier getesteten Gruppen eine hohe Standardabweichung vom Mittelwert beobachtet. Diese könnte möglicherweise, durch die Inhomogenität in der Schmelzsubstanz, die Dicke des Schmelzes, die unterschiedliche Geometrie der mesio-bukkalen Höcker oder durch

Alterungsprozesse entstanden sein [67]. Es muss allerdings betont werden, dass menschliche Schmelzantagonisten am ehesten die klinische Situation nachahmen und in weiteren Studien unbedingt wieder eingesetzt werden sollten.

Leider werden bei den Abrasionsbeständigkeitsprüfungen nur geringfügige oder gar keine Korrelation zwischen den Ergebnissen klinischer Studien und den in-vitro-Untersuchungen gefunden [67]. Der Grund dafür kann die andere Krafteinwirkung und die Frequenz während der Kausimulation sein [17,68-71]. In dieser Studie wird die Alterung durch das zusätzliche Thermocycling verstärkt [67].

Da es sich hier um longitudinale Daten handelt, die über einen längeren Zeitraum beobachtet wurden, kam zur statischen Auswertung die Analyse der gemischten Modelle zur Anwendung. Somit wurde als Baseline einerseits die negative Kontrollgruppe und andererseits die positive Kontrollgruppe gewählt. Durch das Regressionsmodell war es nun möglich, nicht nur die höhe der Materialverluste sondern ebenfalls auch den Anstieg des Materialverlustes zu analysieren und mit der Baseline zu vergleichen.

Als kritisch kann in dieser Studie auf jeden Fall die Wahl der Kontrollgruppen betrachtet werden. Für die positive Kontrolle wurde Glaskeramik gewählt, obwohl es bei den zu testenden Material, um gefüllte und nicht gefüllte Kunststoffe ging. Somit vergleicht diese Untersuchung verschiedene Gruppen von Werkstoffen miteinander. Keramiken sind spröde Werkstoffe, während Kunststoffe sich vor dem Bruch plastisch verformen lassen und somit zu den duktilen Werkstoffen zählen. Die Grundidee von dieser Studie war es, die Abrasionsbeständigkeit von unterschiedlichen CAD/CAM-Kunststoffen in der Erwartung zu testen, in Zukunft Glaskeramik-Rekonstruktionen durch CAD/CAM-gefertigten Kunststoff-Rekonstruktionen zu ersetzen. Allerdings zeigen die CAD/CAM-Kunststoffe heute noch höhere Materialverlustwerte im Vergleich zu Glaskeramik. In Zukunft müssen weitere Studien und Entwicklungschritte durchgeführt werden, um die Abrasionsbeständigkeit der CAD/CAM Kunststoffe zu optimieren.

Heintze [70] setzte sich mit verschiedenen Abrasionsbeständigkeits-messmethoden auseinander wie z.B. der ACTA-, Züricher-, Alabama-, MTS- und OHSU-Messmethode für Füllungskomposite. Gemessen wurde dabei die Abrasionsbeständigkeit nach unterschiedlichen Messmethoden von verschiedenen Kompositen. Alle Messmethoden führten zu verschiedenen Resultaten, die nicht miteinander vergleichbar waren. Auch Tendenzen zwischen den Kunststoffen waren nicht erkennbar. Eine andere Studie beobachtet dagegen geringe Korrelationen zwischen den in-vitro-Studien und den klinischen Daten [72]. Standardisierte in-vitro-Studien sind wichtig, um die Materialien miteinander zu vergleichen und einstufen zu können [17]. Als nächster Schritt sind auf jeden Fall klinische Studien notwendig, um diese Einstufung der Materialien klinisch zu bestätigen.

4. Zusammenfassung und Ausblick

Auf der Grundlage der hier zusammengefassten Untersuchungen konnte festgestellt werden, dass die mechanischen Eigenschaften der CAD/CAM-Kunststoffe durch die standardisierte und kontrollierte industrielle Polymerisation im Vergleich zu konventionellen Kunststoffen verbessert wurde. Zusätzlich kann behauptet werden, dass CAD/CAM-Kunststoffe bei 3-gliedrigen Brücken höhere und stabilere Bruchlastwerte aufweisen als Glaskeramiken. Glaskeramiken erscheinen daher für mehrgliedrige Rekonstruktionen nicht geeignet und sollten ausschließlich nur für Einzelrekonstruktionen eingesetzt werden. Desweiteren wurden bei PMMA-basierten CAD/CAM-Kunststoffen sogar nach einer Lagerungszeit von bis zu 180 Tagen in verschiedenen Flüssigkeiten vergleichbare Farbstabilitäten wie bei Glaskeramiken festgestellt. Ein entscheidender Nachteil der Kunststoffe ist allerdings deren Abrasionsbeständigkeit. Kunststoffe zeigten nach der Alterung im Kausimulator im Vergleich zu Glaskeramik signifikant schlechtere Abrasionsbeständigkeiten. Dabei wiesen PMMA-basierte Kunststoffe signifikant höhere Verscheisswerte auf als Komposite. Beim Betrachten der Schmelzantagonisten erscheinen die Kunststoffe im Vergleich zur Glaskeramik zahnschonender zu sein. Dennoch haben CAD/CAM-Kunststoffe sehr viel Potential. Zur Zeit werden diese Kunststoffe abhängig vom Hersteller für temporäre (bis für einen Zeitraum von 6 Monaten) sowie teilweise für semipermanente (für einen Zeitraum bis zu 2 Jahren) Rekonstruktionen freigegeben. Unbedingt erforderlich ist allerdings eine Optimierung dieser Kunststoffe in Bezug auf die Abrasionsbeständigkeit. Würde dies durch die weitere Änderung der Parameter der Zusammensetzung oder Herstellung gelingen, so könnten sich für kunststoffbasierte Rekonstruktionen in der Zahnmedizin neue Wege erschließen.

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Danksagung

Ich möchte all denjenigen danken, die mir die Arbeit an meiner Dissertation ermöglicht und erleichtertet haben. Ein besonderes Dankeschön gebührt folgenden Personen:

- Prof. Dr. Dr. h.c. Wolfgang Gernet für die Ermöglichung der Vollendung dieser Doktorarbeit sowie für seine immer hilfsbereite Betreuung und tatkräftige Unterstützung bei der Realisierung dieser Arbeit
- Prof. Dr. Christoph Hämmerle für die Möglichkeit der Durchführung der Studien
- Frau Malgorzata Roos, PhD für die immer liebevolle und geduldige statistische Unterstützung
- Frau Beatrice Sener sowie Albert Trottmann für die Unterstützung im Labor bei der Durchführung der Versuche
- Dr. Andreas Ender für die Hilfestellung bei der Bedienung des CAD/CAM Systems Cerec
- Prof. Dr. Mutlu Özcan, PhD für die Hilfestellung beim Schreiben der Manuskripte