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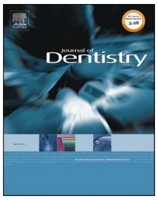

Fracture force and marginal adaptation of additively fabricated resin composite crowns

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A R T I C L E I N F O

Keywords:
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Wear

A B S T R A C T

Objectives: The aim of this study was to compare the in vitro performance and marginal adaptation of additively fabricated resin-based composite molar crowns.

Materials and methods: Molar crowns (n = 8 per group, 9 groups) were 3D-printed from materials for temporary or permanent application. Milled resin based composite crowns were used as a reference. All crowns were adhesively bonded on prepared extracted human molars. Thermal cycling and mechanical loading (TCML) were performed and fracture force was determined. Marginal adaptation was evaluated before and after TCML based on images of the cement gap. Statistics: one-way ANOVA, Bonferroni post-hoc-test ($\alpha = 0.05$).

Results: All crowns survived TCML without failures. Fracture forces of the additively manufactured crowns varied between 1707.9 ± 470.2 N and 2839.6 ± 682.1 N (Reference: 3121.8 ± 557.1 N). Statistical analyses revealed significant ($p \leq 0.004$) individual differences. Fracture pattern was characterized as a fracture of the crown, partially combined with a fracture of the tooth. No visible differences were found in the assessment of margin quality before and after chewing simulation. Signs of wear and scratches were visible at the contact points, but the transitions between the contact points and the crown surface showed no cracks or defects. The perfect margin of the additively manufactured crowns varied between 97.8 % and 100.0 %, before TCML, and between 92.3 % and 99.0 % after TCML.

Conclusion: 3D-printed molar crowns provided sufficient to good in vitro performance and fracture force. Good marginal adaptation was not negatively influenced by in vitro aging.

Clinical relevance: Additively manufactured resin molar crowns on human teeth show adequate fracture resistance, moderate wear, and acceptable marginal adaptation, indicating potential suitability for posterior restorations.

1. Introduction

The widespread implementation of digital workflows in dentistry has accelerated the clinical use of CAD/CAM-fabricated restorations. While subtractive manufacturing is the established standard for permanent crowns, additive manufacturing - primarily based on digital light processing (DLP) - has recently gained relevance following the introduction of 3D-printable resin-based composites [1]. This development is particularly relevant for permanent crowns, where crown fracture remains the most frequent technical complication and mechanical reliability is therefore of critical importance [2]. Recent evidence from a comprehensive systematic review identified 47 different 3D-printed resin materials for single-tooth crowns and reported promising in vitro mechanical performance, including fracture loads exceeding typical masticatory forces [3]. In addition, generally favorable bond strength as well as acceptable marginal and internal adaptation were described. However, the same body of evidence consistently indicates inferior flexural strength, elastic modulus, and surface hardness of 3D-printed resins compared with subtractively manufactured materials [3–5]. Moreover, wide variability in degree of conversion, wear behavior, surface roughness, and biocompatibility has been reported, with post-processing protocols identified as a major influencing factor [6,7]. From a mechanical perspective, resin-based composites exhibit substantially lower elastic moduli [8] and markedly higher water absorption [9] than ceramic materials, which may adversely affect their mechanical performance and limit their indication spectrum. Moreover,

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the reported elution of residual monomers raises concerns regarding material degradation and the long-term integrity of the resin matrix and silane coupling layers.

In vitro studies have demonstrated acceptable performance of milled resin-based crowns [10,11], however, their clinical longevity is influenced by multiple factors, including material composition, preparation design, fit, and cementation [12]. Despite these encouraging results, the available data are predominantly derived from static or simplified laboratory tests. Information on clinical performance, fatigue behavior, wear-induced degradation, and performance after artificial aging remains limited [13–16]. This is of particular concern for resin-based materials, which might be susceptible to water absorption, surface degradation, and cumulative damage under cyclic loading. Especially evidence regarding additively manufactured resin-based crowns remains very limited, and assumptions of comparable performance between additive and subtractive manufacturing techniques are largely based on indirect or insufficient data [4].

Clinical data on permanent crowns fabricated from resin-based materials are currently limited. However, in vitro studies have reported fracture resistance values ranging from approximately 800 to 3000 N. These findings suggest that such restorations may provide mechanically sufficient stability for clinical application under physiological loading conditions [2–4].

Chewing simulation combined with thermal cycling represents a clinically relevant and standardized approach to reproduce occlusal loading, wear, and fatigue under controlled conditions. This methodology allows for a more realistic assessment of long-term functional performance than single-load-to-failure tests and may be therefore essential for critically comparing additively and subtractively manufactured crowns. The application of dynamic loading at clinically relevant crown contact points allows for the evaluation of contact stability and wear characteristics. The properties of the abutment teeth and the bonding can influence the stability of the entire abutment tooth-crown complex: higher moduli of the teeth (e.g., made of metal) and adhesive bonding can increase fracture forces. Further on, the bonding of crowns on human teeth could also enable an assessment of the principally good joint quality of printed crowns [17], based on comparative images taken before and after simulation. Consequently, chewing simulation on human teeth provides a necessary link between promising static in vitro data and clinically meaningful mechanical behavior.

Therefore, the aim of the study was to compare resin-based single tooth crowns on human teeth before and after chewing simulation. The hypothesis of the study was that adhesively fabricated resin-based crowns survive chewing simulation without failure and exhibit comparable fracture strength after chewing simulation. A second hypothesis was that the simulation does not affect the marginal adaption between crown and tooth.

2. Materials and methods

Extracted caries-free human molars (mandibular right first molar, n = 72) were collected and stored in 0.5 % chloramine T (CAS no: 127–65–1, Merck, Taufkirchen, Germany) solution for no longer than 4 weeks. The variability of teeth was respected by preselecting teeth with comparable size and shape and by randomly dividing the teeth to the subgroups. The roots of the molars were coated with a 1 mm layer of polyether impression material (Impregum, Solventum, Seefeld, Germany) to simulate the human periodontium and the resilience of the teeth. Therefore, the roots of the teeth were dipped in wax, which was replaced by polyether in a subsequent fabrication process before the teeth were fixed in sample holders (Palapress Vario, Kulzer, Hanau, Germany). The preparation of the teeth was performed simulating a retentive optimal preparation and fit (height 6–8 mm, angle 6–8°, spacer 80 µm). A 1-mm deep cervical circular shoulder in dentine was prepared and all angles were rounded. The teeth were prepared by one dentist (N. E.) with identical preparation equipment (Diamant, Form W 199 ISO 014, Form W 289 ISO 010, Körnung fein; Henry Schein Dental). Standardized preparation was performed on the basis of an original model, and preparation design was controlled with a gauge. The prepared teeth were digitalized (Cerec Primescan, Dentsply Sirona, Bensheim, Germany) and molar crowns (design: anatomic crown) with identical outer dimensions were designed (Fig. 1). The occlusal and circular wall thickness of the crowns depended on simulated preparation scenario, but in all cases was at least 1.0 mm circular, and the occlusal dimensions varied between 1–1.5 mm. The crowns were fabricated of different materials and fabrication devices specified in Table 1. All crowns were bonded according to the manufacturers' instructions. The inner sides of the crowns were sandblasted (Al_2O_3, 50 µm, 0.2 MPa), treated with a bonding agent (Ceramic Bond, Voco, Germany), and adhesively bonded (resin composite Bifix QM, Voco) to the pre-treated teeth (Futurabond DC, Voco; details see Table 1). All polymerization was performed with Bluephase G4 (Ivoclar, Schaan, FL, 20 s per side).

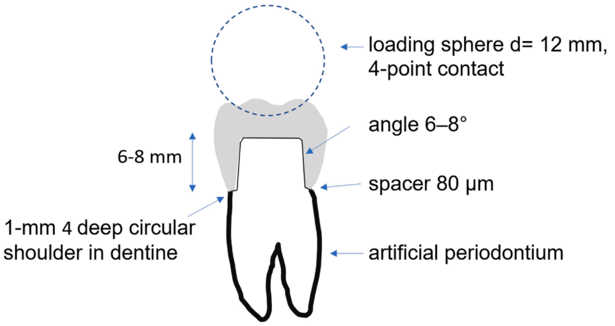

Fig. 1. Preparation and study design.

Crowns were stored for 4 weeks (37 °C) in water and subsequent thermal cycling combined with simultaneous mechanical loading (TCML 3000 × 5 °C/ 3000×55 °C, 2 min each cycle, H_20 distilled;1.2 × 10^6cycles à 50 N, 1.6 Hz) in a chewing simulator (eGo, Regensburg, Germany) was performed. TCML parameters were chosen to simulate five years of oral service. Steatite balls (diameter 12 mm, CeramTec, Plochingen, Germany) were used to standardize antagonists in a three-point-contact situation to the crowns. During TCML, all crowns were controlled daily for failures or fractures. Failed or detached restorations should be excluded from further testing. All crowns that survived TCML were subjected to visual inspection using a digital microscope (VHX, Keyence, Osaka, Japan) at magnifications ranging from ×10 to ×2000, and the contact areas were documented photographically. Fracture force was determined by mechanically loading the crowns to failure in the universal testing machine (Z010, Zwick-Roell, Ulm, Germany). In analogy to chewing simulation, the force was applied in the center of the restorations using a steel sphere (diameter 12 mm, 4-point contact, crosshead speed 1 mm/min). A tin foil (1-mm) was inserted between the crown and sphere to prevent force peaks. The failure determination was set to a 10 % loss of the maximum loading force or acoustic signal (crack). All crowns were optically examined (VHX, Keyence, Osaka, Japan) after fracture testing and the failure mode was documented. The margins of all crowns were digitized using a 3D laser scanning microscope (VK-X100 series, Keyence, Japan) from mesial, distal, buccal and palatial sides. For investigating debonding or marginal degradation, all margins (n = 288; n = 32 per system) were compared before and after TCML. The interface between crown and the tooth-substance were examined (ImageJ, National Institutes of Health, USA). Marginal adaptation was characterized into perfect margin (the two adjoining surfaces show no interruption of the continuous margin and merge into each other without any difference in level) and marginal gap (the two adjoining surfaces show slight imperfections with interruptions in continuity, the forming of gaps or cracks due to loss of cohesion or adhesion). As perfect margin and marginal gap complement each other, only the values for perfect margin are shown.

Table 1
Materials (printing and post-processing were carried out in accordance with the instructions in the respective user information; IPA: 2-Propanol, n.I.: no information available).

Code /Application	Manufacturer	Material		Filler Wt/%	Strength/ Modul	Colour	LOT	Fabrication	Layer	Cleaner	Cleaning	Polymersiation
1 /permanent	Straumann, D	Crown X	Acrylic resin; UDMA; Diphenyl(2,4,6-trimethylbenzoyl)phosphine oxide	n.I.	>50 MPa	A3	243125A	Straumann P30+ Series rapidshape	50 µm	Straumann Prowash	removing adherent resin using a centrifuge:1500 rpm for 2 min. Final cleaning: The component is cleaned under flowing isopropanol for max. 2 min. If necessary, with a brush and spray bottle filled with IPA	Straumann P cure: corresponding material parameter set (Exposure time: 8 min / vacuum 50 mbar / without nitrogen / heater off / power 100 % / wave length 375+415 nm)
2 /permanent	Bego, D	VarseoSmile TriniQ	Esterification products of 4,4′-isopropylidiphenol, ethoxylated and 2-methylprop-2enoic acid, methyl benzoylformate, diphenyl (2,4,6-trimethylbenzoyl)	30–50	120 MPa/ 3.6 Gpa	A1	601,527	ASIGA MAX UV, Dentona; D	50 µm	ultrasonic bath	3 min in reused + 2 min in clean cleaning solution (IPA)	Otoflash G171: 2 × 2000 flashes
3 /provisiona	Voco, D	V-Print c&b temp	TEGDMA, UDMA, diphenyl(2,4,6-trimethylbenzoyl)phosphine oxide	30 .	135 MPa/ 4.4 GPa	A2	#2,517,152	ASIGA MAX UV, Dentona; D	100 µm	hand washing	Remove resin residues with an IPA-soaked brush.	2 × 2000 flashes: Otoflash G171
4 /provisional	Formlabs, D	Premium Teeth	UDMA, Methacrylate Monomer(s), Ethyl phenyl(2,4,6- trimethylbenzoyl)phosphinate	n.I.	155 MPa/ 4.3 GPa		A301241216–01	Formlabs Form 3B	50 µm	Form Wash	Wash for 10 min or until clean (IPA)	Formcure: Cure for 30 min at 80 °C
5 /permanent	Pac-Dent, USA	Rodin Sculpture 2.0	Methacrylic esters, zirconia fillers, pigments, photoinitiators	>60	200 MPa/ 11.7– 14.4 GPa	A1	407,066	ASIGA MAX UV, Dentona; D	50 µm	hand washing	Clean with a paper towel moistened with 99 % IPA. Detailed cleaning: thoroughly clean with a toothbrush soaked in 99 % IPA until a clean, matte surface is achieved.	Otoflash G171: 2 × 2500 flashes under nitrogen
6 /permanent	Detax, D	Freeprint crown	Alkoxylated phenol derivative, methacrylate terminated; 7,7,9(or 7,9,9)-trimethyl-4,13-dioxo-3,14-dioxa-5,12-diazahexadecane-1,16-diyl bismethacrylate; 1,6-hexanedioldimethacrylate; Hydroxy propyl methacrylate; diphenyl(2,4,6-trimethylbenzoyl)phosphine oxide; phenyl bis(2,4,6-trimethylbenzoyl)-phosphine oxide	20–40	>100 MPa/ 3.8 GPa	A3	7275	ASIGA MAX UV, Dentona; D	100 µm	ultrasonic bath	ultrasonic bath: 1 min in IPA + clean openings/cavities with compressed air 1 min in clean cleaning solution (IPA)	Otoflash G171: 2 × 2000 flashes under nitrogen
7 /permanent	Saremco, CH	saremco print CROWNTEC	Esterification products of 4,4′isopropylidiphenol, ethoxylated; 2-methylprop-2enoic acid, initiators	30–50	138 MPa/ >4.0 GPa	SW	E879	ASIGA MAX UV, Dentona; D	50 µm	hand washing	Clean with alcohol-soaked (96 %) cloth and brush until resin residue is completely removed.	Otoflash G171: 2 × 2000 flashes
8 /permanent	Voco, D	Experimental	TEGDMA, UDMA, BisEMA	36	n.I.	A3	V118830	ASIGA MAX UV, Dentona; D	100 µm	hand washing	Remove resin residues with an IPA-soaked brush.	Otoflash G171 2 × 2000 flashes
Refererence /permanent	Voco, D	Grandio disc	TEGDMA, UDMA, BisGMA	87	330 MPa/ 18.2 GPa	A3	2,530,346	Dentsply Sirona inLab MC X5	–	–	–	–

Table 2
Fracture force (N, mean, standard deviation, identical numbers indicate significant differences between the groups, $p < 0.05$) and type and number of fractures (C: crown, CT: crown and tooth, CH: chipping).

	Mean	SD	Fracture pattern
Crown X	2121.0^{1}	516.8	C:8
TriniQ	1751.5^{2}	241.3	C:8
V Print	1888.0^{3}	230.6	C:7, CT:1
Premium Teeth	1833.3^{4}	419.6	C:8
Sculpture 2.0	$2839.6^{2,3,4,5}$	682.1	C:7, CT:1
Freeprint	2186.8^{6}	341.9	C:8
Seramco Print	2177.0^{7}	455.1	C:8
Exp.	$1707.9^{5,8}$	470.2	C:8
Grandio REF	$3121.8^{1,6,7,8}$	557.1	C:6, CT:1, CH:1

Data were controlled for normal distribution (Levene test) and mean and standard deviations were calculated. The statistical analysis was performed using one-way analysis of variance (ANOVA) and the Bonferroni-test for post hoc analysis (SPSS/PC+ software 29.0, SPSS, Armonk, NY, USA). The level of significance was set to $\alpha = 0.05$. A priori power calculation (G*Power3.1.3, Kiel, Germany) provided an estimated power of > 90 % using eight specimens per group.

3. Results

All crowns survived TCML. The homogeneity of variance across the fracture force was confirmed ($p = 0.340$; Levene test). 8 out of the 9 groups demonstrated normal distribution ($p = 0.083$ to 0.560). Fracture forces of the additively manufactured crowns varied between 1707.9 ± 470.2 N (Exp) and 2839.6 ± 682.1N (Sculpture 2.0). The subtractively fabricated reference provided a fracture force of 3121.8 ± 557.1 N (Grandio reference). ANOVA showed a highly significant difference between the groups ($p < 0.001$). Post hoc analyses revealed significant ($p \leq 0.004$) individual differences for specific comparisons (details see Table 2, Fig. 2). Fracture pattern in most was characterized as a fracture of the crown, partially combined with a fracture of the abutment tooth. No differences were found between the groups (Fig. 3).

No visible differences were found in the assessment of margin quality before and after chewing simulation. The chewing simulation did not result in marginal detachment or marginal widening in any cases. Fig. 4 shows representative microscope images of the marginal interfaces on one margin of each crown within the evaluated series. The homogeneity of variance across the marginal adaptation and normal distribution ($p < 0.001$) were confirmed. Before TCML, the perfect margin of the additively manufactured crowns varied between 97.8 ± 12.2 % (Crown X) and 100.0 ± 0.5 % (V Print). The subtractively fabricated reference provided a perfect margin of 100.0 ± 0.2 % (Grandio reference). ANOVA ($p = 0.608$) and post hoc analyses revealed no significant ($p = 1.000$) differences between the individual groups. (Fig. 5). After TCML the perfect margin of the additively manufactured crowns varied between 92.3 ± 21.3 % (Freeprint) and 99.0 ± 7.8 % (Premium Teeth). The subtractively fabricated reference provided a perfect margin of 94.6 ± 19.3 % (Grandio reference). ANOVA showed significant differences between the groups $p = 0.036$), but post hoc analyses revealed no significant ($p = 1.000$) differences between the individual groups. For the

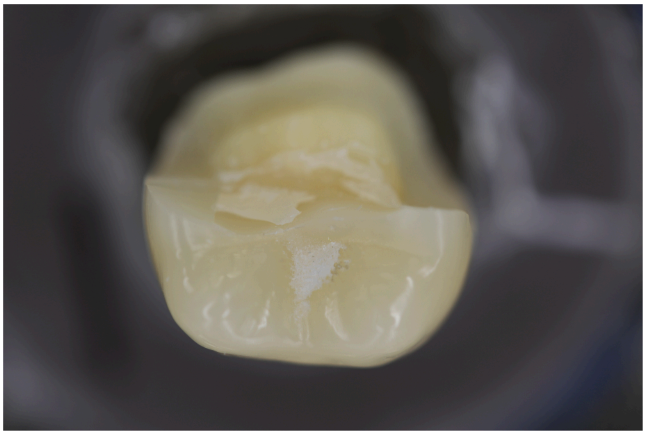

Fig. 3. Typical facture of the crown (occlusal view, example: CrownX).

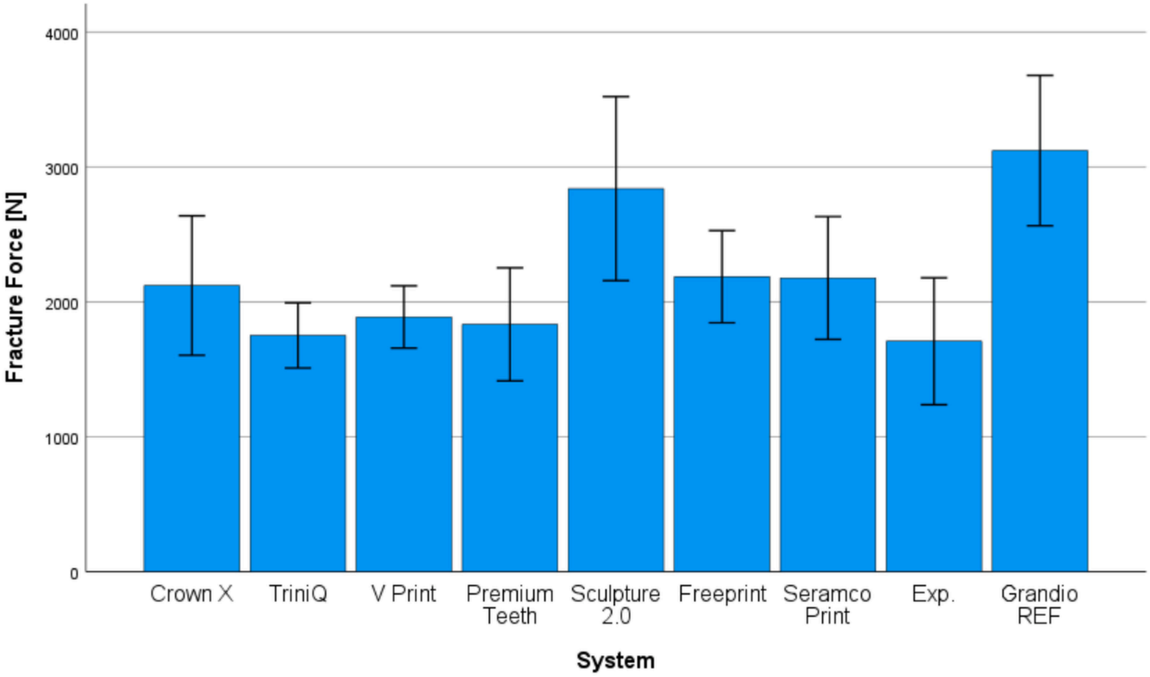

Fig. 2. Fracture force (N, mean, standard deviation, identical numbers indicate significant differences between the groups, $p < 0.05$) and type and number of fractures.

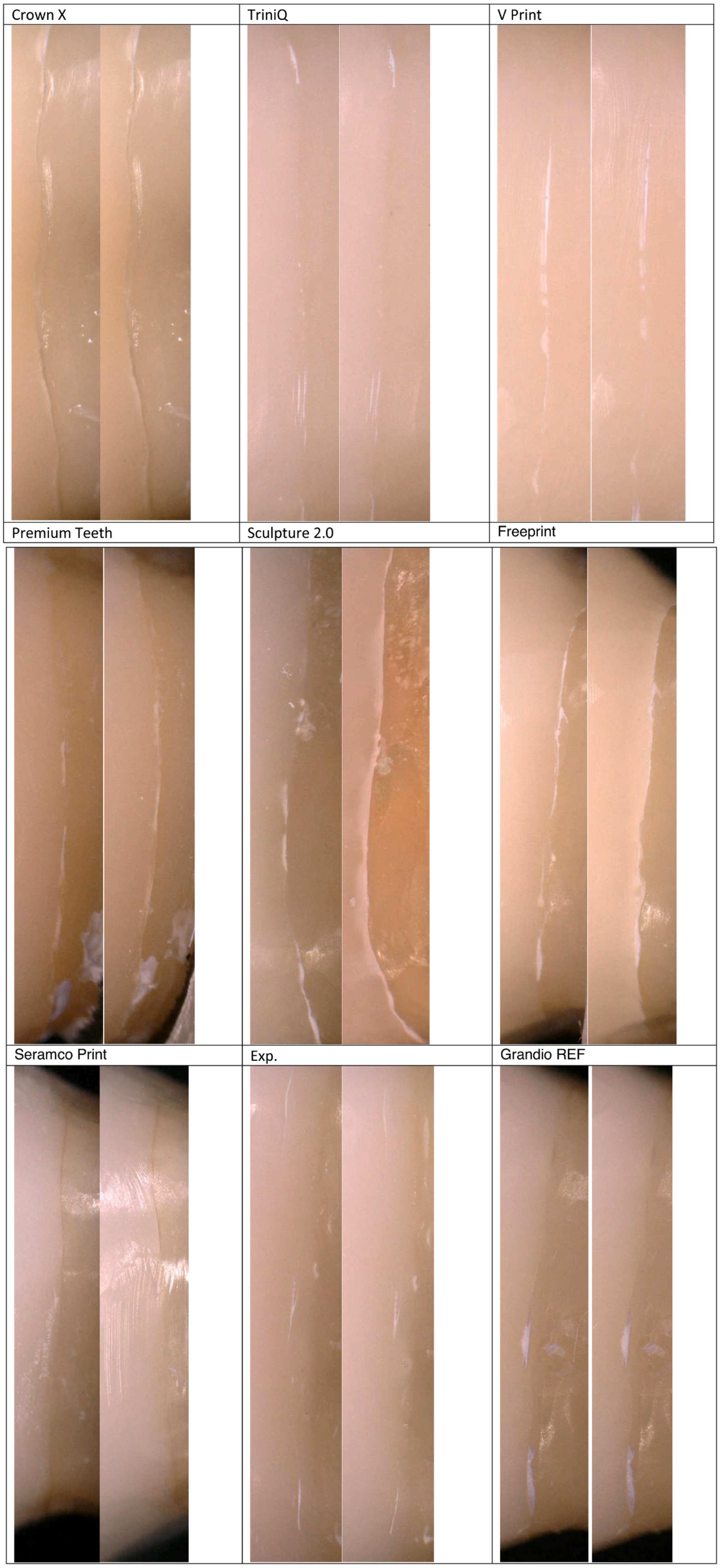

Fig. 4. Marginal adaptation (exemplary pictures before (left) and after (right) thermal cycling and mechanical loading).

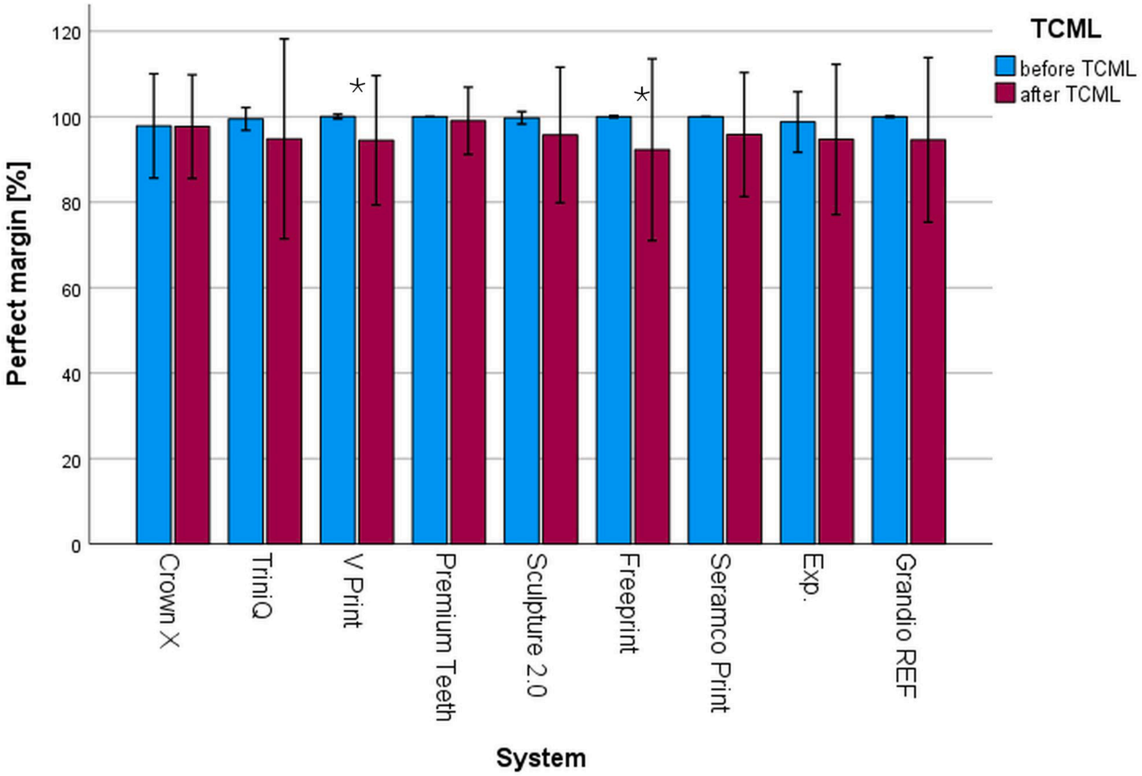

Fig. 5. Marginal adaptation (perfect margin [%]; mean, standard deviation) before and after thermal cycling and mechanical loading; * indicates significant differences $p \leq 0.044$).

materials V Print ($p = 0.042$) and Freeprint ($p = 0.044$), a significant reduction in perfect margin accuracy was observed due to TCML.

The images (Fig. 6) of the contact areas revealed the presence of partially cloudy regions as well as zones exhibiting grinding- and scratch-related features. The contact areas exhibited an approximate diameter of 500 μm. Morphologically, the contacts varied, presenting either oval or angular geometries. This variability is attributable to the individualized fabrication of the crowns. In general, the transition between the contact area and the crown surface was clearly defined and accurately reproduced, with no cracks observed at the interfaces. Nevertheless, isolated images demonstrated minor surface irregularities or microcracks within the contact regions.

4. Discussion

The hypothesis of the study that adhesively fabricated resin-based crowns survive chewing simulation without failure and exhibit comparable fracture strength after chewing simulation could be partially confirmed.

All crowns survived four weeks of water storage and subsequent TCML without visible fractures or debonding. The fracture results of the present study are in a range and consistent with those reported in previous investigations [10,17] or clearly lower [18]. The results may be affected by the crowns' actual occlusal thickness and adaptation [11] as well as the bonding technique and the crown design used [17,19]. Within the tested materials, the highest fracture forces were observed for the subtractively manufactured reference composite crowns, which may be attributed to the material's higher filler content and the associated improvement in mechanical properties (see Table 1). Similarly, among the additively fabricated materials, the material exhibiting the highest filler content and flexural strength also demonstrated the highest fracture force. These findings suggest a positive correlation between filler content, flexural strength, and fracture force, irrespective of the manufacturing technique. Clear correlations cannot be analyzed precisely due to the lack of exact filler content—here, values between 20 and 50 wt% are given. Unfortunately, all tested samples exhibited similar fracture patterns, primarily involving fractures of the crown and, in some cases, the tooth structure. Due to the extensive damage to the crowns following fracture testing, no definitive conclusions can be drawn regarding the origin or specific fracture behavior [20,21]. The higher standard deviations in fracture forces may be attributed to damage to the crowns during simulation, but they could also result from variations in manufacturing process.

However, even the lowest fracture values were around 1700 N, which is even in the range of ceramic or milled composite crowns [22,23] with identical test design. The fact that materials with lower flexural strength exhibit comparable crown fracture values to materials with significantly higher strength, might be related to the creep behavior of these materials. The force–displacement curves, in contrast to ceramics, demonstrated only a slight progressive increase in slope. This non-brittle performance may indicate continuous deformation of the crown materials at the occlusal contact points under fracture loading. A flattening of the contacts could lead to lower surface pressure and thus to a higher fracture force. Accordingly, deformation and adaptation of the crowns under compressive load during fracture testing are likely to occur. Such deformation and adaptation of the occlusal design on the antagonist may contribute to an overestimation of crown stability compared with clinical loading conditions, where clinical stress distribution and loading dynamics differ from those of monotonic fracture testing. This interpretation might be supported by the relatively low hardness and low elastic modulus of the printed materials (<4 GPa) in contrast to milled composites (<20 GPa) or lithiumdisilicate ceramics (<100 GPa) [7]. Although masticatory forces can be incorporated in a relatively straightforward manner into the stability assessment of dental prostheses, the specific modulus of elasticity at which long-term clinical performance may be considered favorable remains insufficiently defined.

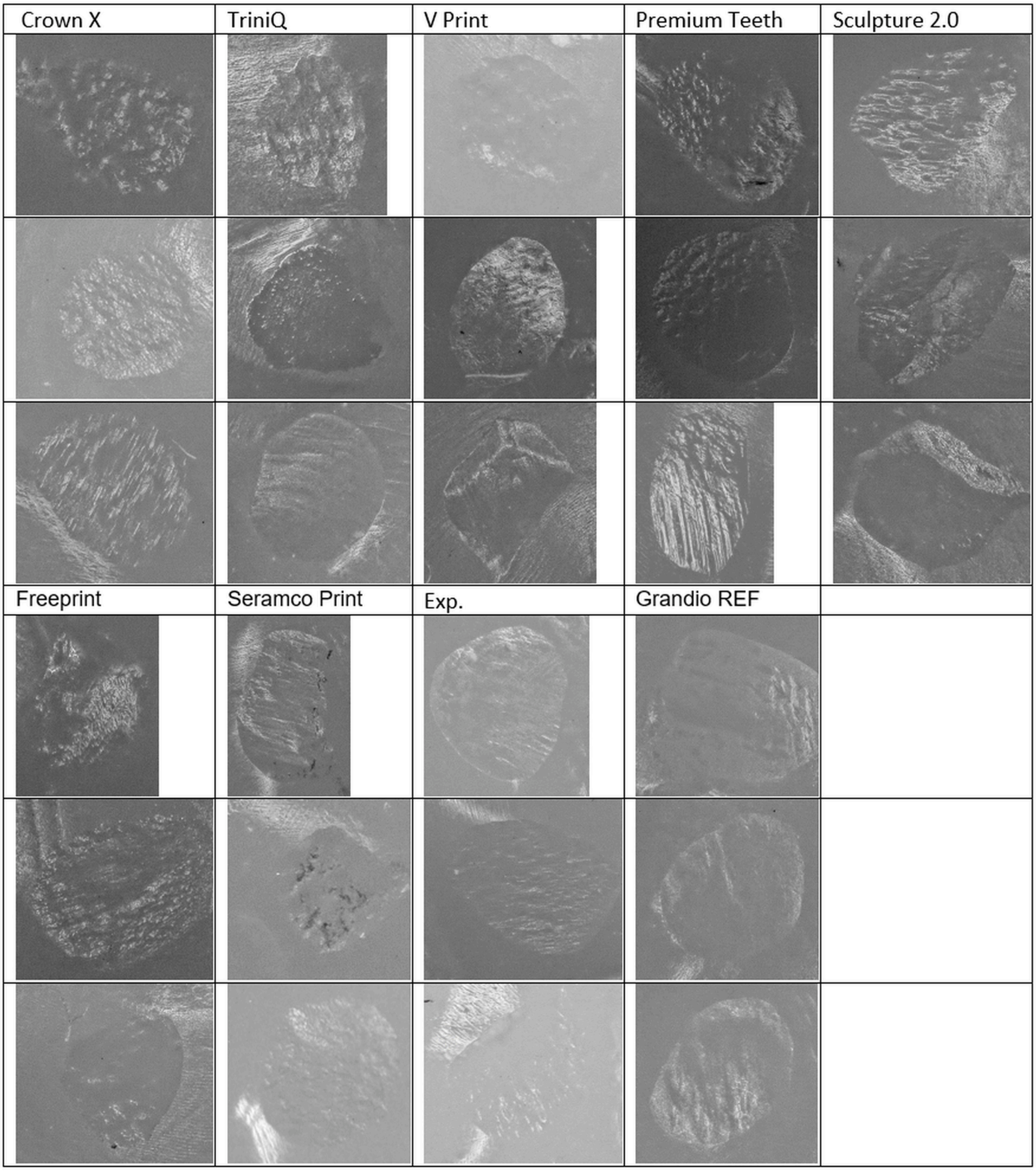

Fig. 6. Exemplary contact points after thermal cycling and mechanical loading.

Fracture testing is therefore primarily employed to evaluate crown integrity following simulation procedures and to identify structural defects, such as microcracks or material damage, that could compromise load-bearing capacity.

The contact areas after TCML were similarly pronounced across all groups. Impulse contacts and micro-scratch patterns were observed, which are likely influenced by the surface roughness and material properties of the antagonists. Similar contact situations but lower wear values in the contacts can also be found for glass ceramics [24]. However, the absence of natural enamel antagonists and the resulting differences in contact conditions represent a limitation of the present study. Standardized occlusal contact which require standardized crown dimensions should therefore be implemented in future investigations to allow a more precise assessment of contact behavior. No or only minor crack formation was detected in the contact areas. Importantly, the observed cracks did not appear to affect fracture force values. Nevertheless, crack formation warrants further investigation, as crack initiation and propagation may pose a potential risk for long-term clinical performance [25]. In particular, it remains unclear whether more brittle materials with higher filler content may be more susceptible to crack development. The origin, depth, and propagation patterns of the observed cracks should be systematically analyzed. Notably, no crack formation was detected in the milled material, raising the question of whether manufacturing technique may influence crack susceptibility. Detailed fractographic analysis, for example using scanning electron microscopy (SEM), is required to clarify these mechanisms [21]. It should also be considered that even well-established restorative materials such as glass ceramics exhibit crack formation in contact areas, suggesting that localized surface damage under functional loading is not uncommon. From a clinical perspective, appropriate polishing methods may be important here [24,26].

The second hypothesis that TCML simulation does not affect the marginal adaption between crown and tooth could be confirmed in parts. Marginal adaptation was good overall after adhesive luting and remained satisfactory in all tested systems after thermocycling and mechanical loading, but two of the materials showed a slight reduction in marginal quality due to TCML. Slight influence of the 4-week water storage could be determined either, although a resin deterioration is expected after water storage [27]. No marginal fractures or signs of delamination were observed. These results suggest a good to sufficient bond between the resin-based composite substrate and the resin-based crown material, ensuring overall stability of the bonded interface. The transition to the natural tooth structure, with the preparation margin located in dentin, also demonstrated good and stable margins following TCML. In similar studies, the marginal quality appears to be just as good as that of lithium disilicate ceramics [28], for example, which have good clinical success rates [29]. However, it remains uncertain whether comparable results would be obtained with different preparation designs [30] or under semi-adhesive bonding conditions [31]. The quality of the bonded interface is influenced by several factors, including marginal fit, cleaning protocol, and clinical accessibility [32]. In the present study, accessibility was optimal due to the absence of adjacent teeth, which represents a limitation with regard to clinical transferability. Even though the marginal results are good, further investigations, such as dye penetration analysis or scanning electron microscopy (SEM), are required to allow a more detailed evaluation of interfacial integrity.

5. Conclusion

Additively manufactured resin molar crowns demonstrate promising in vitro fracture force, capable of withstanding normal and even high masticatory forces in posterior applications. This investigation also indicates generally acceptable marginal adaptation after four weeks of water storage and simulated 5 years of application.

Clinical relevance

Given the limitations of an in vitro study, additively manufactured resin molar crowns may represent a viable option for posterior restorations, as they exhibit sufficient fracture resistance to withstand physiological and elevated masticatory forces. Their good to sufficient marginal adaptation after simulated long-term use suggest potential for reliable clinical performance over time.

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Ethical approval

This article does not contain any studies with human participants or animals performed by any of the authors.

CRediT authorship contribution statement

Nina Edelmann: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Data curation, Conceptualization. **Sebastian Hahnel:** Writing – review & editing. **Angelika Rauch:** Writing – review & editing. **Friedrich Johannes Fleiner:** Writing – review & editing. **Martin Rosentritt:** Writing – review & editing, Supervision, Methodology, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Nina Edelmann declares that she has no competing financial interests or personal relationships. Sebastian Hahnel declares that he has third-party research projects with different dental companies. Angelika Rauch declares that she has third-party research projects with different dental companies. Friedrich Fleiner declares that he has third-party research projects with different dental companies. Martin Rosentritt declares that he has third-party research projects with different dental companies.

Given his role as Editorial Board member, Martin Rosentritt was not involved in the peer review of this article and had no access to information regarding its peer review. Full responsibility for the editorial process for this article was delegated to another journal editor.

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