Original Article

Fracture Resistance Force of Primary Molar Crowns Milled from Polymeric Computer-Aided Design/Computer-Assisted Manufactured Resin Blocks

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ABSTRACT

Purpose: To compare fracture resistance force (FRF) and failure types of crowns milled from resin nanoceramic (Lava Ultimate)-, and modified polymethylmethacrylate (PMMA) (Vita computer-aided design (CAD)-Temp)-, and PMMA (Telio CAD)-based CAD/computer-assisted manufactured (CAM) blocks. **Materials and Methods:** Three experimental groups of 10 milled crowns were arranged: Group-1 (Lava Ultimate), Group-2 (Vita CAD-Temp), and Group-3 (Telio CAD). Crowns were machined in sizes similar to a primary second molar stainless steel crown (SSC) and stored in water at 37°C for 30 days. The crowns were seated on Cr-Co dies. Their FRFs were measured using a universal test machine until fracture. FRFs and failure types were recorded and statistically analyzed ($P < 0.05$). **Results:** There were statistically significant differences among the groups for both FRFs and failure types. The sources of significant differences for FRFs and failure types were Group-3 and Group-1, respectively. **Conclusion:** Crowns milled from different chemical structural CAD/CAM blocks may be used for restoration of primary molar teeth.

Keywords: *Computer-aided design/computer-assisted manufactured resin, fracture resistance force, primary molar crowns*

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Introduction

Stainless steel crowns (SSCs) were introduced by Dr Humphrey into the pediatric dentistry as an indirect restorative resolution in 1950.[1] Over time, clinicians and manufacturers attempted to make some esthetic modifications such as open-faced SSC, chairside-veneered SSC, and preveneered SSC to provide esthetic solutions for their metallic gray-colored appearances.[2-4] In common, the esthetic approaches comprise SSCs and esthetic resin material combinations. The combinations have raised not only some concerns in terms of both human health and environment but also have sometimes provided unsatisfactory resolutions for parents.[5,6] Thus, researches have inclined the development of metal-free esthetic restorations. In the early 1980s, new- invented computer-aided design/computer-assisted manufacture (CAD-CAM) technology was introduced to produce metal-free esthetic restorations.[7] Esthetic restorations are constructed with labside (dental lab-based, dental laboratory production-based, network or open-concept-based model) or chairside (in-office system model) CAD/CAM technologies and milled with alumina, zirconia, and porcelain-based ceramic blocks, metal alloy blocks, and various composite resin blocks.[8] Chairside CAD/CAM technology is more advantageous than labside technology, since both restorations are prepared in a single appointment and also no temporary restorations are used.[8]

Glass-ceramic material that is widely used with CAD/CAM technologies has both advantages such as the esthetic appearance, color stability, biocompatibility, and life-long durability and disadvantages such as

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brittleness, tendency to fracturing, and attrition on the enamel of the antagonist tooth.[9-13] To overcome its disadvantages, resin nanoceramic (RNC)-, modified polymethylmethacrylate (PMMA)-, or PMMA-based polymeric resins have been developed under high temperature and pressure.[14-17] The polymeric materials have some advantages[12,15,18,19]: they are less worn by the antagonist tooth enamel, their low modulus of elasticity enables them to absorb the functional stresses, they have a higher degree of conversion due to lower rate of residual monomer, and they require less invasive chamfer and bevel preparation types.

Although the studies have been conducted in relation to fracture resistance force (FRF) of crowns milled for permanent teeth, no results for primary molar crowns have been reported. The objective of this study was to compare occlusal FRFs and failure types of primary molar crowns milled from RNC-, modified PMMA-, and PMMA-based CAD/CAM blocks for in-office system model. The null hypothesis was that no significant difference would be found with regard to FRFs and failure types among primary molar crowns machined from the CAD/CAM blocks such as RNC-, modified PMMA-, and PMMA-based blocks.

Materials and Methods

Abutment preparation

Irreversible hydrocolloid impression material was placed in a plastic molds. #E2 (crown for primary second molar) SSCs (3M and ESPE, Seefeld, Germany) were immerged into the impression material up to 10 mm. The impression material was waited to be set. Inner surfaces of the SSCs in the impression material were sealed using Vaseline® (Lever Faberge GmbH, 21614 Buxtehude, Germany). Both the inner surfaces of the SSCs and the entryway were filled with molten casting wax. After the wax pattern has set, it was removed from the dental impression material. Furthermore, the SSCs were delicately removed from the wax pattern. The preparations of the patterns were made as follows: occlusal surface was reduced by 1–1.5 mm and buccal, lingual, mesial, and distal surfaces were reduced by 15°–20° angle without any undercut remained. Gingival margin line was reduced by preparing a 0.5 mm bevel. Suitability of the wax pattern preparation was checked through the #E2 SSC on the wax pattern. Later, Cr-Co alloy metal dies were fabricated from the wax patterns. The cast dies were sandblasted using aluminum oxide particles. The cast abutment dies were embedded in acrylic resin up to 1 mm below the prepared gingival margin line and used for FRF test procedure of each crown.

Milling of the crowns from computer-aided design/computer-assisted manufactured blocks

The crown materials for the study are listed in Table 1. Lava Ultimate, Vita CAD-Temp, and Telio CAD CAD/CAM blocks were selected to mill the crowns.

The crown designs were made in CEREC AC Acquisition Unit using CEREC 4.0 software (Sirona Dental Systems GmbH, Bensheim, Germany) since the program offers the use of biogeneric design technique (the software has data on all permanent tooth forms; however, it additionally scans the adjacent teeth to copy their characteristics). Permanent first molar forms were referenced due to their similarity to the forms of the primary second molars. Restoration type was selected as full crown. Biogeneric copy design was used as the biogeneric design technique [Figure 1a-c].

CEREC MC XL (Sirona Dental Systems GmbH, Bensheim, Germany) was selected as the milling unit. The brand and type of the polymeric CAD/CAM resin block that would be used in the milling process were chosen and marked.

Optical impressions of the cast abutment dies were acquired by CEREC Omnicam (Sirona Dental Systems GmbH, Bensheim, Germany). Since biogeneric copy was used as the biogeneric design technique, to standardly simulate the morphologies of the teeth before the preparation, optical impressions of #E2 SSC were also acquired [Figure 2a and b]. Crowns were designed based on this order.

After the optical impression process, models of the cast abutment dies and biogeneric copies of the SSCs were screened on the liquid-crystal display monitor. They were examined, and undesirable model areas were lined and cut out. Gingival margins of the restorations were manually plotted [Figure 2c].

Acquired virtual models were dropped into the dental arcs in the standard image catalog of the software in accordance with their natural positions. Biogeneric copies are automatically obtained by the system [Figure 2d].

For this *in vitro* study, since the impressions were taken over a single tooth, the proximal and occlusal contact force parameters determined by the system were eliminated. The parameters used for this study were minimal radial thickness = 1700 µm, minimal occlusal thickness = 1700 µm, and cement spacer = 80 µm. Crown design was made through the guidance of biogeneric copy [Figure 3].

Designed crowns are automatically dropped into as one crown for each Lava Ultimate CAD/CAM block [Figure 2e] and three crowns for each Vita CAD-Temp and Telio CAD blocks [Figure 2f].

Soon after the restoration design had been completed, bur and block were placed in CEREC MC XL milling unit. By pushing the "start" button on the CEREC AC unit, milling process was begun in the CEREC MC XL milling unit. When the restoration was completely machined, the blocks were retrieved from the milling unit's chamber, and the restorations were cut out of the blocks. Specimens had been waited at 37°C for 30 days until the test period.

Grouping

Group 1: Passive seatings of every crown that was milled out of Lava Ultimate blocks on the prepared Cr-Co cast-die were fit-tried. Each crown was cemented onto one of the cast abutment dies using temporary luting cement (Calcimol, Voco, Cuxhaven, Germany). The crown was held on the cast die under a constant force of 5 kg/f for 4 min.

Group 2: Every crown in the group was prepared by the milling of Vita CAD-Temp polymeric blocks, and passive seating on the cast abutment die was fit-tried. Next steps were conducted in the same methodology of Group-1.

Group 3: Passive seatings of the crowns milled from Telio CAD blocks were tried on the die-casted abutments. Crown cementation procedure was similar to those in Group-1.

Fracture resistance force test and failure types

#E2 (crown for primary second molar) SSC was immerged into the irreversible hydrocolloid impression material up to 10 mm. The SSC was removed from impression material after the impression material was set. The hollow was filled with molten casting wax. The wax pattern was removed from the impression material. Cr-Co alloy metal jig was fabricated and sandblasted using aluminum oxide particles. Using the fabricated Cr-Co loading jig, load tests were carried out. Load was applied on the occlusal surfaces of the crowns with a header rate of 1.5 mm/min (AGS-5kNG; Shimadzu Co., Kyoto, Japan) and the force required was recorded in newtons. Loading had continued until failures such as split-fracture (score 1), rupture, or plastic deformation (score 2) were detected on the crown materials and the obtained data were recorded in Newton.

In addition, failures occurred were photographed under a stereomicroscope with ×10 magnification (Nikon SMZ-V multipoint-sensor system, Japan).

Statistical analysis

All analyses were carried out using SPSS 20.0 for Windows (SPSS, Chicago, IL, USA). The FRFs obtained from three materials were compared by using one-way analysis of variance and *post hoc* Duncan multiple comparison tests. Fracture types were compared using Chi-square test. The significance level was set at $P < 0.05$.

Results

The mean FRF values are given in Table 2. It is seen in the table that mean FRF values change from 866.8 to 898.1 newtons. One-way ANOVA revealed significant differences among the groups in terms of FRF test (F = 20.798 P <005). To understand the source of this significance, Duncan *post hoc* multiple comparison test was used. The distribution of FRFs occurred as

Figure 1: Choosing the tooth number for the upper (a) and lower (b) primary second molar crowns, restoration type, and biogeneric design method (c)

Table 1: Materials, compositions, and manufacturers as used in the study

Materials and batch number	Compositions	Manufacturers
Lava Ultimate (70201086348)	20% UDMA resin, 80% nanoceramic (silica nanomers, zirconia nanomers, nanocluster particles derived from the nanomers), silane coupling agent	3M and ESPE, St. Paul, Germany
Vita CAD-Temp (EC42M2TCT402)	Acrylic polymer with 14% microfiller. Microfilled reinforced polyacrylate	Vita Zahnfabrik, Bad Sackingen, Germany
Telio CAD (627722)	99.5% PMMA polymer	Ivoclar Vivadent, Schaan, Liechtenstein

UDMA=Urethane dimethacrylate; PMMA=Polymethylmethacrylate

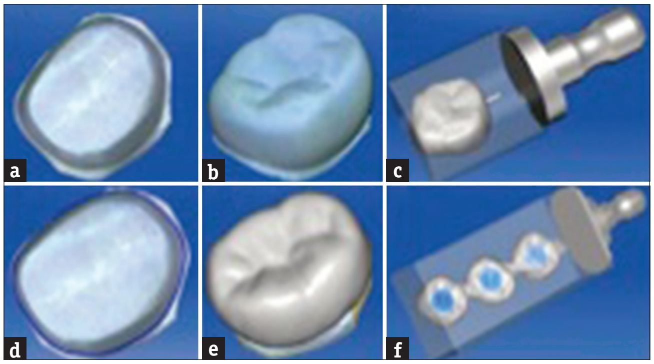

Figure 2: Screen shot scanned from the lower primary second molar cast abutment die (a); biogeneric copy of the lower #E2 stainless steel crown (b); conforming the margins of the crown (c); designing the lower primary second molar crown (d); virtual positioning scenario for the crown inside the Lava Ultimate block (e); virtual positioning scenarios for the crowns inside the Vita computer aided design-Temp and Telio computer-aided design blocks (f)

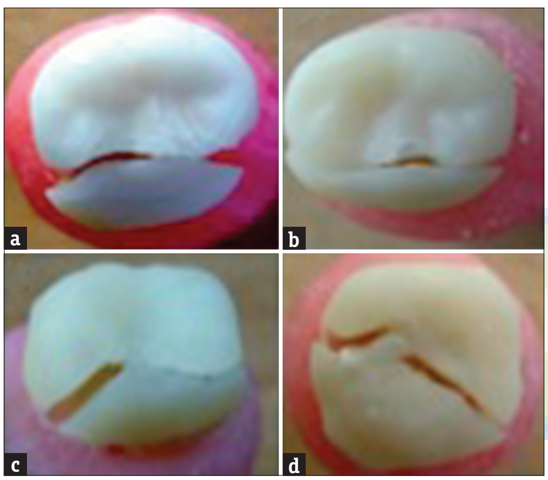

Figure 4: Crowns displaying score 1 failure types; Lava Ultimate (a and b), Vita computer-aided design-Temp (c), and Telio computer-aided design (d) (×10)

Table 2: The mean fracture resistance force values and failures types of the crowns

Groups	*n*	The mean FRF values of the crowns (newton±SD)	The scores of failure types	
			Fracture	Plastic deformation
Group-1^{a,A}	10	898.1±81	10	-
Group-2^{a,B}	10	866.8±80	6	4
Group-3^{b,B}	10	1245.1±94	4	6

^{a,b}The differences among the FRF values of the groups marked by the same letter are not statistically significant (P>0.05); ^{A,B} The differences among the failure types of the groups marked by the same letter are not statistically significant (P>0.05). FRF=Fracture resistance force; SD=Standard deviation

follows: Group-3 > Group-1 = Group-2. That is, the mean FRF obtained from the crowns machined from Telio CAD was significantly higher than those of both Lava Ultimate and Vita CAD-Temp (P < 0.05).

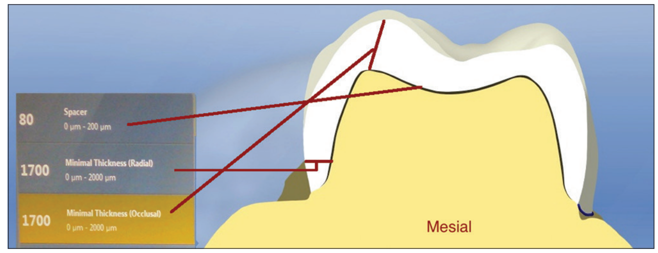

Figure 3: Measurements and dimensions for the crown designing

Figure 5: Crowns demonstrating score 2 failure types; Lava Ultimate (a and b), Vita computer-aided design-Temp (c), and Telio computer-aided design (d) (×10)

The fracture types observed are showed in Table 2 and Figures 4a-d and 5a-d. When all three fracture types were compared, the difference among the groups found to be statistically significant (χ^2 = 8.459; P < 0.02). The source of the statistical difference was Group-1, and "fracture" failures (score 1) were noted in all of the crowns in this group [Figure 4a and b]. Although there was no significant difference between Group-2 and Group-3, "plastic deformation" failures (score 2) in Group-3 were slightly higher than those of Group-2 [Figure 5a-d].

Discussion

Although *in vitro* studies are considered as a sign of clinical achievement, they might not completely prove the clinical expectancies since the clinical conditions could not be fully simulated. They provide the clinicians foreknowledge for deciding about the use of tested materials. From this point, the authors compared the FRFs of the crowns for the primary second molar, which were milled out of three different CAD/CAM resins. The differences between both the FRFs obtained from the groups and the fracture types were found statistically significant (P < 0.000). The null hypothesis stating, "there was no significant difference between the FRFs and failure types of primary molar crowns machined from the CAD/CAM blocks such as PMMA-, modified PMMA-, and RNC-based" has been rejected.

Morphological variations and irregularities of the natural tooth and the amount of the remaining dentin tissue after the preparation may influence the fracture resistance of the crowns.[20] To eliminate the situation, artificial abutments with standardized preparation forms were used for this study. Stawarczyk *et al*.[11] stated that in the FRF tests, fixed dental prosthesis might be tested by seating on the abutments without using cement. The moduli of elasticity of the abutments and cement have an influence on the fracture resistance of the restoration.[21,22] As the modulus of elasticity of the abutment increases, the fracture resistance of the restoration raises.[23] The cement may absorb the applied forces. Thus, the authors seated the PMMA-, modified PMMA-, and RNC-based CD/CAM crowns on the Cr-Co alloy abutments without adhesive.

PMMA synthetic polymers introduced in the 1930s are widely used in dentistry. These materials can be divided into the linear (e.g., PMMA) and the cross-linked polymers (e.g., Bis-GMA, TEGDMA, and UDMA). They have been used for crowns milled out of polymeric blocks in CAD/CAM technology as well as dentures, fillings and adhesive materials, and sealants.[24]

Stawarczyk *et al*.[11] found that Vita CAD-Temp specimens had lower FRFs than those of Telio-CAD. The result was in accordance with the present study. This may be explained by the organic structures of CAD/CAM blocks.[25,26]

Telio CAD is a high strength prefabricated monomethacrylate-based PMMA, and it has long-chain-shaped linear molecules, which are slightly cross-linked.[25] Being an acrylate polymer, Vita CAD-Temp has vinyl groups in which 2 carbon atoms double bonded to one another and also attached to the carbonyl carbon. Since the double bonds are very reactive and display low strength, acrylates easily form polymers.[25] Furthermore, H_2O molecules diffuse the spaces among the polymer chains and make them apart.[25] Yao *et al*.[25] stated that water physically weakened Vita CAD-Temp more than Telio CAD.

Alt *et al*.[18] found that the FRFs of the crowns milled from composite resin blocks containing UDMA, reduce as long as the crowns have been soaked in water. In this study, similar results were obtained from the crowns machined by using Lava Ultimate blocks because they were stored in water for 1 month before the testing. These findings may be attributed to hydrolytic degradation of the UDMA resin matrix of the Lava Ultimate. Polymers that contain urethane-based monomer system have hydrophilic tendency since their carbamate linkage may develop hydrogen bonds with water. Matsukawa *et al*.[27] and Kerby *et al*.[28] stated that using UDMA monomers could be an effective method for reducing the water sorption of urethane-based polymers.

The crowns milled from CAD/CAM blocks may show good clinical performance in primary molar teeth because they have resistance to fracture under the forces that were greater than the average biting force of 5–10-year-old children (375 newtons).[29] The limitation of the study was that the loads were only axially applied. Parafunctional movements and lateral forces occurred in the mouth were not simulated.

Either deformation or fracture occurred on the crown material on which the load applied through the primary second molar shaped Cr-Co jig. If both surfaces (crown and jig) were rigid, fractures occurred on the crown material. Having been one of the surfaces, if the crown material had a ductile structure, it might absorb more functional stress through the plastic deformation.[30,31] There were significant differences between the fracture types in this study [Table 2]. The authors consider that the filler ratio of the materials (Lava Ultimate 80% nanoceramic filler particles; Vita CAD-Temp 14% microparticle filler; Telio CAD no filler) and surface hardness (Lava Ultimate = 2.5 GPa; Telio CAD = 180 MPa; Vita CAD Temp = 210 MPa) may contribute to these differences. High resin ratio and low filler rate cause deformation on the material rather than the fracture.[32] On the PMMA- and modified PMMA-based crowns, deformation may be observed instead of fracture. The fracture failures noted in all of the specimens may be explained by the higher surface hardness of the Lava Ultimate in comparison to the other materials used in the study.

Conclusion

Within the limitation of this study, CAD/CAM crowns milled for the primary molars promised to be used as an alternative for the full-coronal coverage. However, clinical studies are needed to support their use in the primary molar teeth restorations.

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Conflicts of interest

There are no conflicts of interest.

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