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Pilot Study of Tooth Structure Removed in Primary Molar Zirconia Crown Preparations of Typodont Teeth

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Abstract

Prefabricated zirconia crowns (ZRCs) require a passive fit and more reduction than stainless steel crowns (SSC). To determine the mean and maximum reduction depths in the mesial-buccal and occlusal areas for three ZRC brands and one SSC in posterior primary typodont molars and to compare reduction depths to existing literature to determine the preparation's proximity to pulpal tissue. Four primary maxillary and mandibular typodont teeth (J and S) were prepared according to the manufacturers' guidelines for three ZRCs and an SSC. The teeth were scanned before and after preparation with an optical scanner, and the mean and maximum depths of reduction for each tooth were calculated in triplicate with custom software and statistically compared among the types of crown. The results were compared to existing data on primary tooth enamel and dentin thickness. Maximum mesial-buccal and occlusal depth respectively of preparation for any ZRC for tooth J was 1.19 mm and 1.58 mm while for tooth S it was 1.06 and 2.07mm Both EZ Crowns and Kinder Krowns required an additional 0.5mm occlusal reduction beyond the manufacturer's recommendation for tooth S. Ideal preparations of ZRCs require more reduction than SSCs. Both EZ Crowns and Kinder Krowns require more reduction than the manufacturer's recommendation for a mandibular first primary molar.

Keywords
Pediatric dentistry; primary molars; zirconia; zirconia pediatric crown

1. Introduction

Stainless Steel Crowns (SSCs) have been the restorative material of choice for multi-surface restorations since 1950 [1]. When comparing the failure rates of SSCs to those of amalgam or composite restorations, SSCs are superior in their durability and longevity [2, 3]. SSCs have effectively been used for grossly carious teeth, those with significant wear or developmental defects, following pulpal therapy, and as an abutment for a space maintainer [4]. Despite the history of clinical superiority of the SSC, there are some negative aspects such as poorly fitting margins or hypersensitivity reactions in some children [4]. A primary drawback of the SSC is poor esthetics which is a major concern for parents [5, 6]. The introduction of the pre-veneered SSC with white facing was an attempt to keep the durability of the SSC and improve the esthetic aspect. However, the pre-veneered SSC has been shown to be prone to fracture of the esthetic facing, which would leave the stainless steel exposed, thus diminishing the desired esthetic results [7].

Prefabricated zirconia crowns (ZRC) have increased in popularity and are significantly more esthetically pleasing to parents. In several parental surveys, ZRCs receive a high acceptance rating for esthetics [8-10]. Two clinical studies examining ZRCs in comparison to SSCs in posterior teeth have found ZRCs and SSCs to be clinically comparable [10, 11]. In the Taran and Kaya study, ZRC had lower plaque index and gingival index scores compared to SSCs at 12 months of follow up [11]. Two ZRCs decemented and one fractured; all SSCs were retained. In the Donly et al. randomized controlled trial, researchers compared the two restoration types in eleven different clinical categories at 24 months of follow up and determined that the only major difference between the two options was an overwhelming approval from parents for esthetics of the ZRCs [10]. The need for pulpal therapy was not an exclusion criterion; however, none of the teeth required pulpal therapy, and all of the teeth that were available at follow up were clinically successful [10].

While ZRCs are esthetically more pleasing, they also require significantly more reduction than SSCs [12]. Additionally, practitioners are unable to crimp or adjust ZRCs to adapt to the margins of the tooth; all brands of ZRCs require a passive fit [13-15]. Previous research by Clark et al. has shown that a posterior primary tooth requires twice as much reduction compared to an SSC [12].

However, the Clark study determined differences in weight of typodont teeth as a surrogate measure of tooth reduction and did not identify specific areas of reduction (ie. occlusal areas close to pulp horns). To achieve a passive fit, clinicians have a tendency to over-reduce the tooth beyond the clinical guidelines that are recommended by the manufacturer [16]. Currently, no studies examine the extension of the ZRC preparation and the potential for pulpal involvement. Clinicians would be interested in knowing how much margin of error they might have if the preparation deviates from the ideal ZRC preparation, especially since pulp horns are higher in primary molars compared with permanent molars [17].

The purpose of this pilot study was to determine the mean and maximum reduction depths in the mesial-buccal and occlusal areas for three ZRC brands and one SSC brand in posterior primary molars and to compare reduction depths to existing literature to determine the preparation's proximity to pulpal tissue.

2. Materials and Methods

2.1 Initial Typodont Tooth Dimensions and Crown Size Selection

Eight primary typodont teeth, four maxillary left second primary molars (J) and four mandibular right first primary molars (S), (Kilgore International, Inc. Coldwater, MI, USA) were used. The eight unprepared primary typodont teeth were initially scanned to determine each tooth's dimensions using an optical scanner (COMET xS, Steinbichler Optotechnik GmbH, Neubeuern, Germany). Three commercially available posterior ZRC brands and one SSC brand were utilized: 1) NuSmile ZR Zirconia (NuSmile, Houston, TX, USA); 2) EZCrown Zirconia (Sprig, Loomis, CA, USA); 3) Kinder Krowns Zirconia (Kinder Krowns, St. Louis Park, MN, USA); and 4) Stainless Steel Crown Primary (3M ESPE, St. Paul, MN, USA). Based on the mesial, distal, buccal, and lingual dimensions of typodont teeth S and J an appropriate crown size from each manufacturer was selected to achieve a passive fit (Table 1).

Table 1 Typodont teeth dimensions, selected crown sizes, and ideal manufacturers' preparation instructions for zirconia and stainless steel (SSC) crown preparations.

	M-D Width	B-L Width	Crown Size	Preparation Instructions	
Typodont Tooth S	8.6 mm	6.7 mm			
SSC	8.2 mm	6.9 mm	D5	Occlusal Reduction: Mesial-Distal Reduction: Buccal-Lingual Reduction: Subgingival Margin:	1-1.5mm Slice None Feather
NuSmile	8.9 mm	7.3 mm	D5R	Occlusal Reduction: Mesial-Distal Reduction: Buccal-Lingual Reduction:	1.0-1.5mm 0.5-1.25mm Reduce

					20%
				Subgingival Margin:	Feather
EZCrowns	8.1 mm	7.4 mm	S5	Occlusal Reduction: Mesial-Distal Reduction: Buccal-Lingual Reduction: Subgingival Margin:	1.5 mm 1.0 mm each 1.0 mm each Feather
Kinder	8.9 mm	7.1 mm	S5	Occlusal Reduction: Mesial-Distal Reduction: Buccal-Lingual Reduction: Subgingival Margin:	1.0-1.5 mm 0.85-1.5 mm 0.85-1.5 mm Feather
Typodont tooth J	9.2mm	9.6mm		Same instructions as listed above.	
SSC	9.1mm	10.2mm	E3		
NuSmile	8.8mm	9.8mm	E2L		
EZCrowns	8.9mm	10.2mm	J2		
Kinder	9.2mm	10.5m	J2		

2.2 Typodont Tooth Preparation

The typodont teeth were then ideally prepared according to the manufacturers' guidelines (Table 1, also previously published in Clark et al. [12]) by following a systematic protocol utilizing depth guides. Typodont teeth were placed into a typodont and an impression putty (Affinis Perfect impressions, Coltene/Whaledent, Cuyahoga Falls, OH, USA) was used to create depth reduction guides. Two separate putty molds were made for each tooth with one cut in a mesial-distal direction and the other in a buccal-lingual direction.

A #330 bur (Komet FG#330, Rock Hill, SC, USA) was used for initial 1 mm occlusal depth cuts; a diamond football bur (Komet FG023, Rock Hill, SC, USA) was used for occlusal reductions; and a tapered diamond bur (Komet FG012, Rock Hill, SC, USA) was used for the interproximal, buccal, and lingual reductions. The same three burs were used for all crown preps. The teeth were initially reduced according to the recommended manufacturers guidelines. To ensure that gross reductions did not occur on the teeth; the sectioned putty molds and a periodontal probe were used to measure and adjust the reduction of the teeth to the appropriate dimensions to achieve the proper "snap on" fit for the SSC and the passive fit for the ZRCs. If the appropriately sized ZRCs did not achieve a passive fit after the initial guideline preparations; the teeth were incrementally reduced until the crowns achieved a passive fit. Occlude Aerosol Indicator Spray (Pascal Company, Inc., Bellevue, WA, USA) was applied to the intaglio surfaces of the zirconia crowns and placed on the prepared teeth. The teeth were only reduced in the areas where the spray was visible, making sure to avoid over-reducing the typodont teeth. Once a passive fit was achieved, the opposing typodont was placed into occlusion to ensure all teeth were occluding appropriately. Once occlusion was achieved, the preparations were considered complete.

2.3 Typodont Tooth Dimensions after Preparation

The eight prepared primary typodont teeth were rescanned with the COMET xS Optical Scanner. The pre- and post-preparation scans were aligned using Cumulus software (Copyright Regents of the University of Minnesota, Minneapolis, MN, USA). The software determined an optimal fit by minimizing the root-mean-square differences of the unchanged reference surfaces (root portion) and fit 90 percent of the points with within 5 µm. Once the scans were aligned, a custom developed software was used to determine the mean and maximum depths of the preparations on the occlusal surface and on the mesial-buccal (MB) surface (Figure 1). The occlusal surface was selected as an area of measurement in order to estimate the remaining dentin thickness above the mesial pulp horn. The MB surface was selected because the MB line angle may be one of the most reduced areas of the coronal portion of the crown for the ZRC preparation because of the prominent bulge. The area selection was done in triplicate. One-way ANOVA statistics followed by Student-Newman-Keuls post-hoc tests at 0.05 significance level were used to compare differences in the mean and maximum depths among the crown preparations (SuperANOVA, Abacus Concepts Inc, Berkeley, CA).

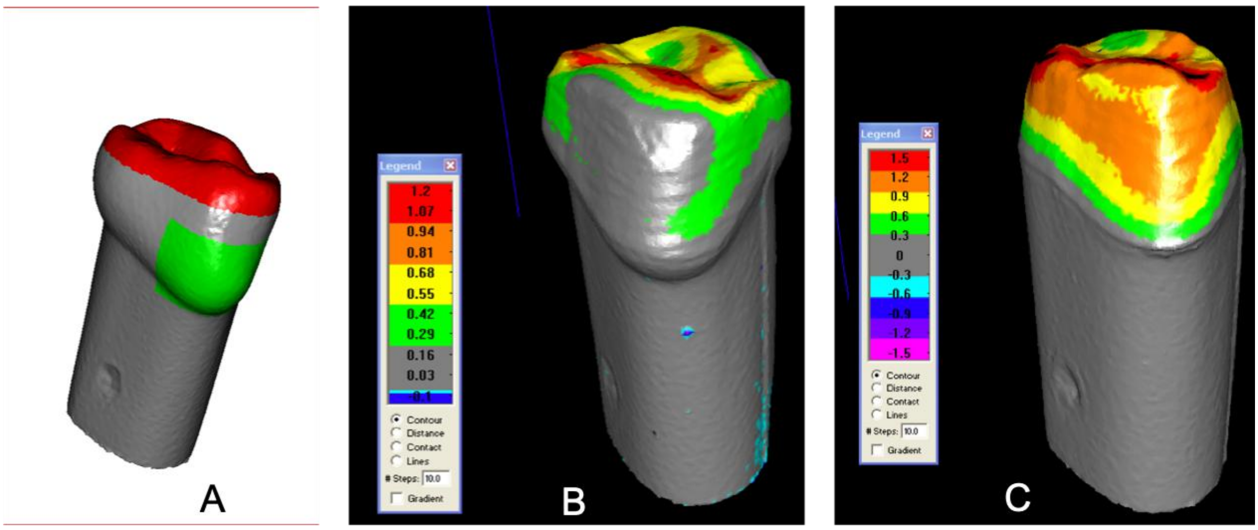

Figure 1 Typodont tooth S scanned with COMET xS Optical Scanner. The area to be measured was selected from the scan of an unprepared tooth with occlusal surface highlighted in red and buccal surface highlighted in green (A). Tooth S prepared for a stainless steel crown (B) had less reduction than a tooth prepared for a zirconia crown (Kinder) (C). Colors on the coronal portion represent depths of tooth reduction in mm according to the color scale.

2. 4 Comparing Maximum Preparation Depths to Existing Hard Tissue Thickness Measurements

Previous research has used micro-computed tomography to determine the average enamel and dentin thickness of maxillary primary second molars and mandibular primary first molars [17-21]. Considering the enamel and dentin thicknesses reported in the literature18,20, the total hard tissue thickness (enamel and dentin) on the buccal surface of tooth J is 4.039 mm and of tooth S is 3.383 mm (Table 2). The maximum depths of each preparation were compared to the existing hard tissue thickness measurements for primary teeth.

Table 2 Average thickness of enamel and dentin of primary mandibular first molars (Tooth S) and primary maxillary second molars (Tooth J) [17, 19, 21].

		Mesial (mm)	Distal (mm)	Buccal (mm)	Lingual (mm)
# J	Enamel	0.713±0.14	0.96±0.15	1.033±0.11	0.827±0.18
	Dentin	2.13±0.22	2.192±0.23	3.006±0.23	2.73±0.43
	Total Hard Tissue Thickness	2.843±0.36	3.152±0.38	4.039±0.38	3.557±0.61
	Occlusal measurement: Distance from Mesial Buccal Cusp tip to Pulp Chamber Ceiling (mm)				4.84±0.51
# S	Enamel	0.893±0.12	0.867±0.14	0.953±0.10	0.893±0.14
	Dentin	1.655±0.19	1.664±0.54	2.43±0.11	1.869±0.41
	Total Hard Tissue Thickness	2.548±0.31	2.531±0.68	3.383±0.21	2.762±0.55
	Occlusal measurement: Distance from Mesial Buccal Cusp tip to Pulp Chamber Ceiling (mm)				3.34±0.69

3. Results

3.1 Tooth Reduction

The mean and maximum reduction depths of the occlusal and mesio-buccal areas for each tooth and each crown type are reported in Table 3. The greatest areas of tooth reduction for all teeth preparations occurred on the occlusal and mesio-buccal surfaces of the teeth. The maximum depth of preparation on the occlusal surface for any ZRC for tooth J was 1.58 mm while for tooth S it was 2.07 mm. The SSC required the least amount of tooth reduction while the ZRC reductions were all within 0.5 mm of each other. For both areas of measurement, Kinder Krowns ZRC required the most reduction for tooth S while the EZ Crown and Kinder Krowns required more reduction than NuSmile ZR crown for tooth J. Both Kinder Krowns ZRC and EZ Crowns required more occlusal reduction than the manufacturer's recommendation of 1.0-1.5 mm [14, 15], which was more than 0.5 mm for the occlusal surface of tooth S. The maximum mesial-buccal depth of reduction of any preparation was 1.19 mm for tooth J and 1.06 mm for tooth S. The SSC preparation required less than half of the mesial-buccal reduction required for any ZRC.

Table 3 Mean and maximum depths (mean±standard deviation) of reduction of prepared typodont teeth (Tooth J and S) for the SSC and ZRCs.

Crown	Tooth #J		Tooth #S	
Type	Occlusal	Mesiobuccal	Occlusal	Mesiobuccal

	Mean Depth	Max Depth	Mean Depth	Max Depth	Mean Depth	Max Depth	Mean Depth	Max Depth
SSC	0.69±0.02 A	1.22±0.00	0.06 ±0.01 A	0.45±0.03 A	0.74±0.02 A	1.34±0.00 A	0.12±0.01 A	0.33±0.02 A
EZCrowns	1.11±0.01 C	1.58±0.00	0.54±0.06 B	1.13±0.02 C	1.39±0.05 C	2.00±0.00 C	0.42±0.02 B	0.74±0.00 B
NuSmile	0.91±0.00 B	1.43±0.00	0.52±0.03 B	1.02±0.00 B	1.04±0.03 B	1.63±0.00 B	0.44±0.05 B	0.80±0.00 C
Kinder	0.90±0.01 B	1.55±0.00	0.62±0.12 B	1.19±0.06 C	1.39±0.01 C	2.07±0.00 D	0.73±0.05 C	1.06±0.01 D

Different letters indicate significant difference among crown types (one-way ANOVA followed by Student-Newman-Keuls post hoc tests at 0.05 significance level).

3.2 Proximity to the Pulp Chamber

The occlusal measurement from the mesial buccal cusp tip to the pulp chamber has been reported in previous literature to be 4.84 +/- 0.51 mm for tooth J and 3.34 +/- 0.69 mm for tooth S. The largest maximum depth of occlusal reduction was for Kinder Krown ZRC at 2.07 mm, indicating sufficient tooth structure remaining for pulpal protection if the tooth is ideally prepared.

4. Discussion

Remaining tooth structure after crown preparation is necessary for crown retention and pulpal protection [22]. Laboratory data has shown that at least 2 mm of remaining occluso-cervical height is crucial for crown retention [22]. The ideal preparation of the occlusal surface of any ZRC for teeth J and S should not exceed approximately 2 mm which would ensure adequate wall height for retention. However, this study was unable to evaluate how extensive caries, in which a large portion of tooth structure is already missing, may alter occlusal reduction and affect retention.

Remaining dentin thickness (RDT) has been found to be an important factor in mediating pulpal inflammatory activity with a minimum of 0.5 mm RDT recommended for tertiary repair activity [23, 24]. The maximum mesial-buccal depth of reduction of any preparation was 1.19 mm for tooth J and 1.06 mm for tooth S, indicating sufficient remaining tooth structure for pulpal protection. For occlusal reduction, the results of this pilot study support that a mechanical pulp exposure on a maxillary second molar is unlikely even if the practitioner is slightly more aggressive than the manufacturer recommends. However, for the primary mandibular molar, the practitioner has less margin of error. If 0.5 mm of RDT is required, the practitioner has approximately 1 mm of margin of error for two of the brands of ZRCs. Both EZ Crowns and Kinder Krowns ZR have altered intaglio surfaces to increase mechanical retention with cements while NuSmile ZR utilizes chemical bonding with its recommended cement [25]. The two brands which have altered intaglio surfaces may require more reduction to account for this alteration in the crown design.

Recent clinical data suggests ZRCs are promising for full coverage restoration of primary teeth [8-10]. The study by Donly and colleagues used a split-mouth design and reported no periapical pathology after 24 months with ZRC or SSC restoration. The study examined the NuSmile brand of ZRC which, in the current study, had the lowest value of maximum depth of reduction of all the brands. Though pulpal therapy was not an exclusion criterion, none of the teeth required pulpal treatment. However, the study did not report how many of the teeth were primary mandibular first molars versus other primary molars. The results of this pilot study suggest that pulpal inflammation and/or pathology could potentially occur in the mandibular primary first molar if the practitioner were more aggressive than the ideal preparation recommendations.

This study had several limitations inherent to in vitro studies. The study teeth were typodont teeth which allowed comparison between brands of ZRCs since they were the same dimensions, but typodont teeth may not represent human primary dentition accurately. The process for obtaining the ideal preparation with the use of matrices and disclosing spray is not clinically relevant. Additionally, the study design assumes intact to mildly cavitated lesions and does not address the reduction of grossly carious teeth. Only one tooth per group was used because the typodont teeth were carefully prepared to ideal specification, which in essence is not variable. The typodont teeth were the same dimensions and the preparation method was standardized which ensures that reduction measurements could be compared across brands. The aim of the pilot study was to obtain baseline reduction data for various brands of ZRCs was therefore met. A future study could compare reduction measurements in more samples by simulating the clinical situation in which practitioners “eyeball” their reduction and re-try the ZRC until a passive fit is obtained which could potentially result in over-reduction.

This pilot study gives the practitioner baseline data for how much tooth structure is removed from the occlusal and MB portion of two types of primary molars for various brands of ZRCs. Practitioners must reduce the MB aspect of the tooth more aggressively they do for SSCs. For two brands of ZRCs, EZCrowns and Kinder Krowns ZR, a clinician has approximately 1 mm “margin of error” for a primary mandibular first molar’s occlusal reduction given the hard tissue thickness of the tooth is 3.34 +/- 0.69 mm and the ideal reduction was 2 mm. As practitioners incorporate ZRCs into their practices, understanding differences in brands may aid clinicians in their use of the material or in their selection of restorative materials.

5. Conclusions

Ideal preparations of ZRCs require more reduction than SSCs. Both Kinder Krown ZRCs and EZ Crowns require more reduction than the manufacturer’s recommendation for a mandibular first primary molar.

Author Contributions

AV, DT, and MW conceived and planned the experiments. CW carried out the experiment. AV performed the computations and DT verified the analytical methods. MW helped supervise the project. CW wrote the manuscript with support from AV, DT, and MW. All authors discussed the results and contributed to the final manuscript.

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Competing Interests

The authors have declared that no competing interests exist.

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