Three-Dimensional Digitalized Surface and Volumetric Analysis of Posterior Prefabricated Zirconia Crowns for Children

Hyeonjong Lee*/ Yong Kwon Chae**/ Hyo-Seol Lee***/ Sung Chul Choi ****/Ok Hyung Nam*****

Objectives: *This study was designed to compare the surface morphologies and volumes of posterior prefabricated zirconia crowns and posterior stainless steel crowns (SSCs) using digitalized three-dimensional (3D) reconstructed images.* ***Study design:*** *We tested prefabricated zirconia crowns (NuSmile ZR; Orthodontic Technologies, Houston, TX, USA) and SSCs (Kids Crown; Shinhung, Seoul, Korea) used to restore left maxillary and mandibular molars. A Rainbow scanner (Dentium, Seoul, Korea) was used to digitise the inner and outer surface morphologies of all crowns. The data were superimposed and evaluated using 3D software. The differences between the outer and inner surfaces and inner volume were measured.* ***Results:*** *The differences between the two types of crowns differed by tooth surface. At the occlusal surface, the differences were greater at the cusp tip than the fossa. At the axial level, the differences decreased toward the gingival margins. Also, relative volumetric ratios varied.* ***Conclusions:*** *Tooth preparation prior to placement of prefabricated zirconia crowns requires special consideration. Greater amounts of tooth reduction are necessary for posterior zirconia crowns than for SSCs. The occlusal surface requires more tooth reduction than the axial surface and the gingival margin.*

Keywords*: Dental Crowns; Prefabricated Zirconia Crown; Pediatric Zirconia Crown; Volumetric analysis; Three-dimensional imaging*

INTRODUCTION

Early childhood caries (ECC) is a serious public health problem affecting children both functionally and psychologically. ECC affects all parts of the primary teeth and can destroy their structures. Severely affected primary molars are usually indicated for full-coverage restoration.[1] For decades, stainless steel crowns (SSCs) have served as the gold standard for full-coverage restoration of primary molars. SSCs are prefabricated crowns, which differs in that they are delivered through try-in errors and set with marginal crimping without the impression taking and additional laboratory process as in typical permanent teeth crowns. SSCs are mechanically strong and reduce the rate of secondary caries, but fail to fulfil the esthetic desires of pediatric patients and their guardians.[2,3]

Recently, prefabricated zirconia crowns for primary teeth have become available (Figure 1). They can be an effective alternative restoration option, enhancing aesthetics and exhibiting good biocompatibility.[4,5] As prefabricated zirconia crowns cannot be crimped for adjustment, dental practitioners should prepare the teeth to fit the zirconia crowns. Therefore, primary teeth that are to receive such crowns require more reduction than those to be fitted with SSCs. Currently, at least four commercial zirconia crowns for pediatric patients are available, but the manufacturers provide limited tooth-reduction guidelines for pediatric dentists.[6]

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Figure 1. Currently available pediatric zirconia crowns.

Crown	Company	Composition	Size
NuSmile ZR®	NuSmile Ltd., Houston, Texas, USA	Zirconium oxide 88 - 96% Yttrium oxide (Y_2O_3) 4 - 6% Hafnium oxide (HfO_2) 5% etc.	1-6
Cheng Crowns®	Peter Cheng Orthodontic Laboratories, Inc., Exton,Pa., USA		
Kinder Krowns®	Mayclin Dental Studios, Minneapolis,Minn., USA		
EZ Pedo® Crown	EZ-Pedo, Inc., El Dorado Hills, Calif., USA		

Efforts have been made to optimize tooth preparation prior to placement of prefabricated zirconia crowns.[6–8] Clark *et al.*[7] compared the tooth reductions required prior to placement of such crowns and SSCs. They manually prepared primary typodont teeth and found that tooth weight loss was greater when prefabricated zirconia crowns were placed. However, because they only compared weight losses after tooth preparation, they did not provide details on surface-specific reductions.

Appropriate tooth preparation is important to ensure the long-term stability of prefabricated zirconia crowns. Therefore, the purpose of the present study was to compare the surface morphologies and the actual volumes of posterior prefabricated zirconia crowns and posterior SSCs and to provide tooth preparation suggestions for pediatric zirconia crowns using digitalized three-dimensional (3D) reconstructed images.

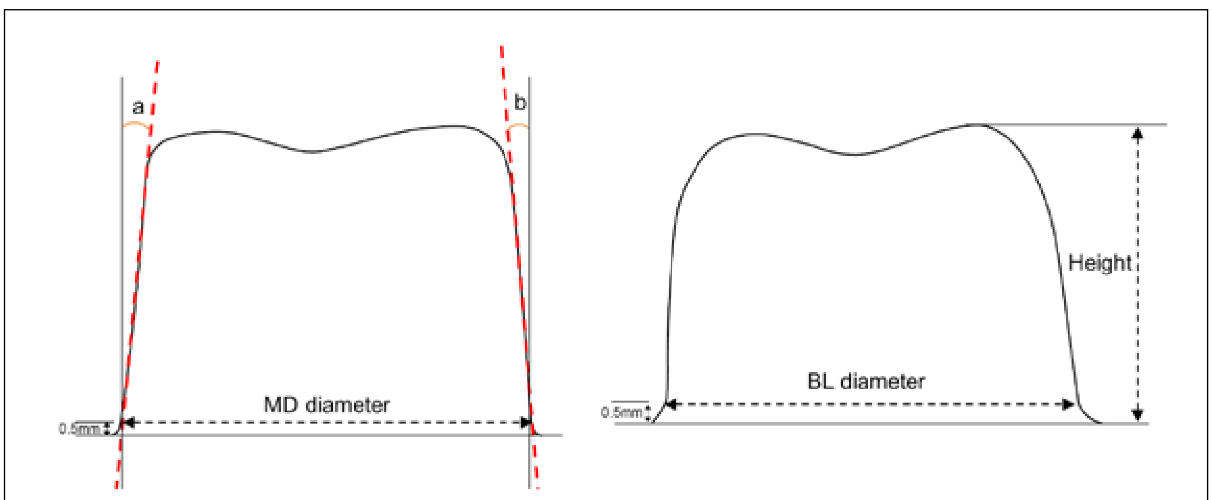
MATERIALS AND METHOD

We evaluated prefabricated zirconia crowns (NuSmile ZR; Orthodontic Technologies, Houston, Texas, USA) and SSCs (Kids Crown; Shinhung, Seoul, Korea) for the primary maxillary and mandibular left molars (crown sizes 3, 4, and 5). First, we evaluated the mechanical tolerance of each zirconia crown and SSC. Five zirconia crowns and five SSCs for maxillary first primary molars were randomly selected. Then each crown was scanned using laboratory scanner (T500, Medit, Seoul, Korea) and anti-glare spray (CEREC Optispray, Sirona, Bensheim, Germany). Precision of each group was analyzed by calculating root mean square (RMS) value based on ISO 12836 (ISO12836:2015-Dentistry-Digitizing devices for CAD/CAM systems).

A Rainbow scanner (Dentium, Seoul, Korea) was used to yield digital scans of the inner and outer surfaces of all crowns. First, the inner surfaces were reproduced as polyvinylsiloxane (PVS) impressions (Imprint 3; 3M ESPE, Maplewood, MN, USA). Then, CEREC Optispray was sprayed onto the outer surface to prevent reflection during scanning. The scan included polymerized PVS below the crown. Next, the crown was carefully removed and the PVS surface representing the inner surface of the crown was scanned and saved as a STL file.[9,10] All scans were imported into 3D analysis software (Gom Inspect 2017; GOM, Braunschweig, Germany) and the following measurements were obtained (Figure 2):

- Mesiodistal (MD) diameter: The longest distance between the mesial and distal surfaces;
- Buccolingual (BL) diameter: The longest distance between the buccal and lingual surfaces;
- Height: The distance from the inferior point of the gingival margin to the superior point of the cusp tip on the buccal surface;
- Taper: The average angle between a line parallel to the long axis of the tooth and a line tangent to the mesial and distal walls of the outer surface.

Figure 2. Schematic drawing of outer measurements. Mesiodistal (MD) and buccolingual (BL) distance was the longest distance measured at 0.5mm above the margin. Height was measured the distance from the inferior point of the gingival margin to the superior point of the cusp tip on the buccal surface. Taper was calculated the average of degree a and b.



We superimposed the inner and outer surfaces of all crowns using the PVS extruded from underneath the crowns as the reference. The superimposed data were aligned on the x, y, and z axes, and the differences between the inner and outer surface were measured at the cusp tip (four most superior points), three most inferior points of the fossa, eight points (at half-crown height) of the axial wall, and eight points at 0.3 mm above the gingival margin (Figure 3). The inner surfaces of each crown were clearly cut at the margin and holes were filled by the same algorithm, then volume of each crown was calculated (3-Matic; Materialise, Leuven, Belgium) (Figure 4). We compared the actual volumetric data of crowns by relative volumetric ratio. Relative volumetric ratio was calculated by actual volume of each crown size per the actual volume of the smallest size of prefabricated zirconia crown.

RESULTS

The mechanical tolerance of each prefabricated zirconia crown and SSC is shown in Figure 5. The RMS value was 0.015±0.004 mm in the prefabricated zirconia crown and 0.017±0.006 mm in the SSC.

The measurement data are shown in Tables 1 and 2. The outer surfaces of prefabricated zirconia crowns of all sizes were less than those of equivalently sized SSCs. For prefabricated zirconia crowns, 3D analyses revealed inner/outer surface differences of 0.78±0.06 mm at the cusp tip, 0.57±0.05 mm on the fossa, 0.63±0.09 mm at the axial wall, and 0.34±0.05 mm at the gingival margin. The values for SSCs were 0.26±0.02 mm at the cusp tip, 0.26±0.02 mm on the fossa, 0.19±0.02 mm at the axial wall, and 0.17±0.02 mm at the gingival margin (Figure 6). At the occlusal level, the differences

Figure 3. Reference points used in the present study. Discrepancy between the outer and inner surfaces was measured at each point. Four points (1–4) served as references for the cusp tip; there were 5–7 for the fossa, 8–15 for the axial wall, and 16–23 for the gingival margin.

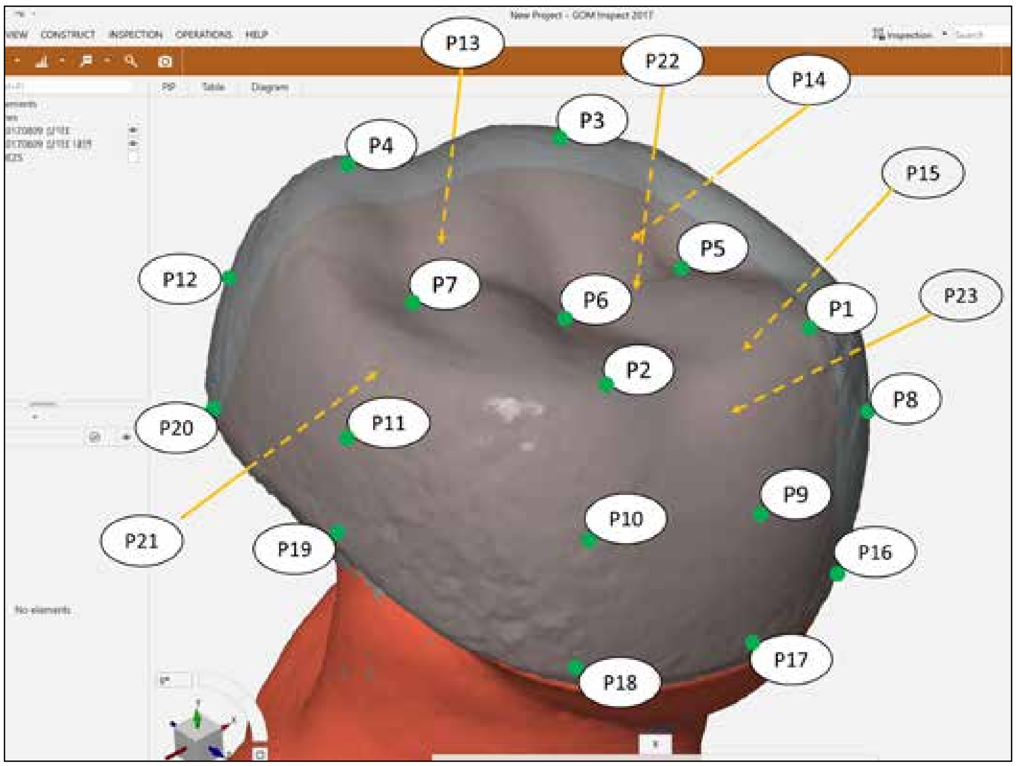
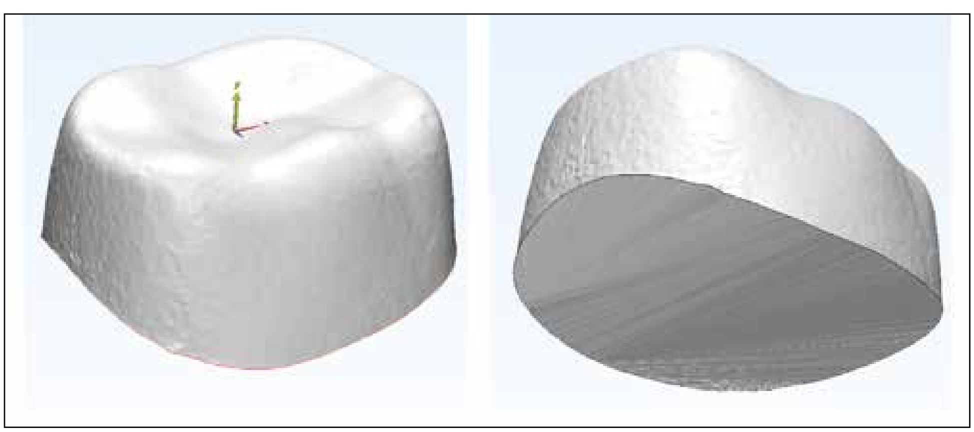


Figure 4. Three-dimensional (3D) reconstruction of inner surface data. 3D volumetric analysis of each crown was performed by 3D reconstruction of the inner surface data. The sample images above are a prefabricated zirconia crown for mandibular second primary molar.



were greater at the cusp tip than on the fossa. At the axial level, the differences decreased toward the gingival margins. The 3D superimpositions of the inner and outer surfaces of the two crowns are shown in Figure 7.

The inner volumes of prefabricated zirconia crowns of all sizes were smaller than those of equivalently sized SSCs. Relative volumetric ratios of crowns are shown in Figure 8. Relative volumetric ratios between two types of same sized crown varied. Also, relative volumetric ratios between different sized crowns of two types of crowns varied.

Table 1. Crown outer surface measurements

Tooth No.[1]	Crown	Size	MD[2] (mm)	BL[3] (mm)	Height (mm)
#64	Zirconia crown	3	7.29	7.70	4.33
		4	7.90	8.44	5.01
		5	8.13	8.85	5.25
	SSC[4]	3	7.10	8.25	4.78
		4	7.25	8.64	4.94
		5	7.43	8.91	5.07
#65	Zirconia crown	3	9.23	10.51	5.64
		4	9.78	11.02	5.81
		5	10.21	11.42	6.13
	SSC	3	9.63	10.26	5.65
		4	9.92	10.98	6.04
		5	10.43	11.39	6.27
#74	Zirconia crown	3	10.12	9.03	5.06
		4	10.62	9.45	5.40
		5	10.92	9.86	5.63
	SSC	3	10.04	9.17	5.24
		4	10.25	9.50	5.46
		5	11.50	9.98	5.66
#75	Zirconia crown	3	8.31	6.74	4.39
		4	9.03	7.32	5.25
		5	9.38	7.50	5.44
	SSC	3	8.28	6.74	5.36
		4	8.62	6.99	5.39
		5	9.02	7.42	6.07

[1]According to FDI notation, [2]Mesiodistal, [3]Buccolingual, [4]Stainless steel crown

Figure 5. Comparison of root mean square (RMS) values for evaluating mechanical tolerance of the crowns.

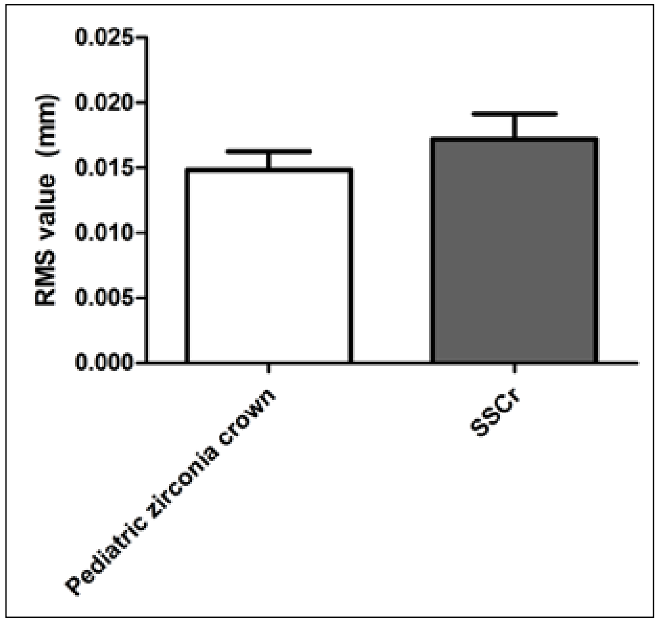


Table 2. Crown inner surface measurements

Tooth No.[1]	Crown	Size	MD[2] (mm)	BL[3] (mm)	Height (mm)	Taper (degree)	Volume (mm³)
#64	Zirconia crown	3	6.38	6.96	4.03	8.2	98
		4	6.63	7.33	4.36	8.3	116
		5	6.95	7.63	4.66	7.7	130
	SSC[4]	3	6.83	7.84	4.39	-10.6	151
		4	7.21	8.11	4.68	-11.1	157
		5	7.38	8.45	4.81	-10.8	180
#65	Zirconia crown	3	8.02	9.62	4.65	13.7	198
		4	8.61	10.15	4.68	13.3	241
		5	8.95	10.31	5.28	13.5	259
	SSC	3	8.81	9.65	5.31	-8.6	257
		4	9.43	10.23	5.43	-8.9	312
		5	9.85	10.72	5.79	-9.1	347
#74	Zirconia crown	3	7.23	6.25	4.03	13.6	105
		4	8.04	6.43	4.48	13.3	131
		5	8.32	6.85	4.68	13.5	155
	SSC	3	7.84	6.58	5.27	-5.1	149
		4	8.11	6.88	5.28	-5.1	158
		5	8.49	7.31	5.68	-5.3	203
#75	Zirconia crown	3	8.71	7.78	4.15	10.1	186
		4	9.02	8.08	4.31	10.9	213
		5	9.51	8.64	4.64	10.5	245
	SSC	3	9.27	8.42	4.87	-6.1	244
		4	9.79	8.93	5.21	-6.3	273
		5	10.07	9.22	5.61	-6.4	327

[1]According to FDI notation, [2]Mesiodistal, [3]Buccolingual, [4]Stainless steel crown

Figure 6. The three-dimensional (3D) discrepancy between the outer and inner surface of each crown. (a) Cusp tip, (b) fossa, (c) axial wall, (d) gingival margin. Abbreviations: UPFZ=Zirconia crown for upper primary first molar, UPSZ=Zirconia crown for upper primary second molar, UPFS=Stainless steel crown for upper primary first molar, UPSS=Stainless steel crown for upper primary second molar, LPFZ=Zirconia crown for lower primary first molar, LPSZ=Zirconia crown for lower primary second molar, LPFS=Stainless steel crown for lower primary first molar, LPSS=Stainless steel crown for lower primary second molar.

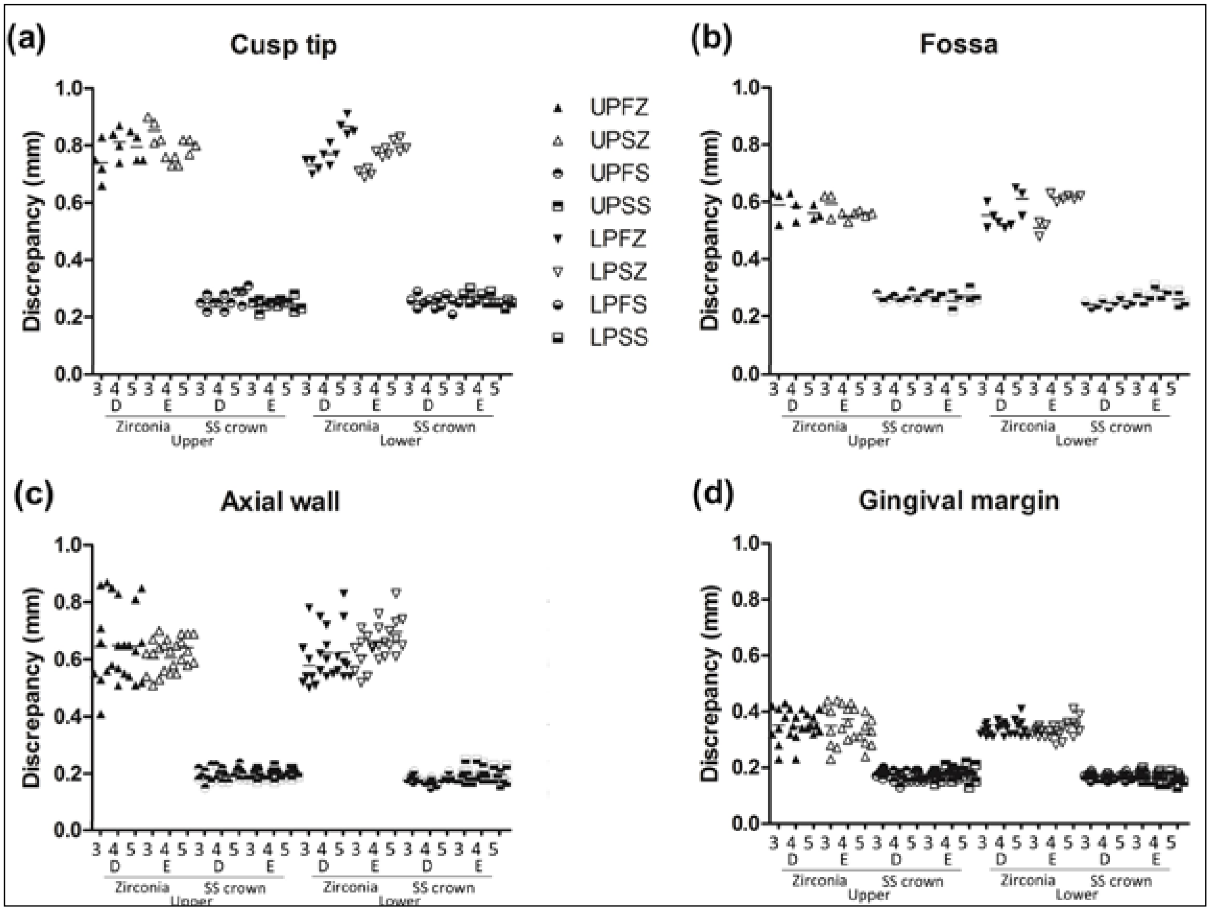


Figure 7. Color-coded difference images obtained via three-dimensional analyses of the inner and outer surfaces of prefabricated zirconia and stainless steel crowns in pediatric patients. Inner/outer surface difference of each crown is given for different colors. Color-coded difference is shown with discrete color step in every 0.04 mm.

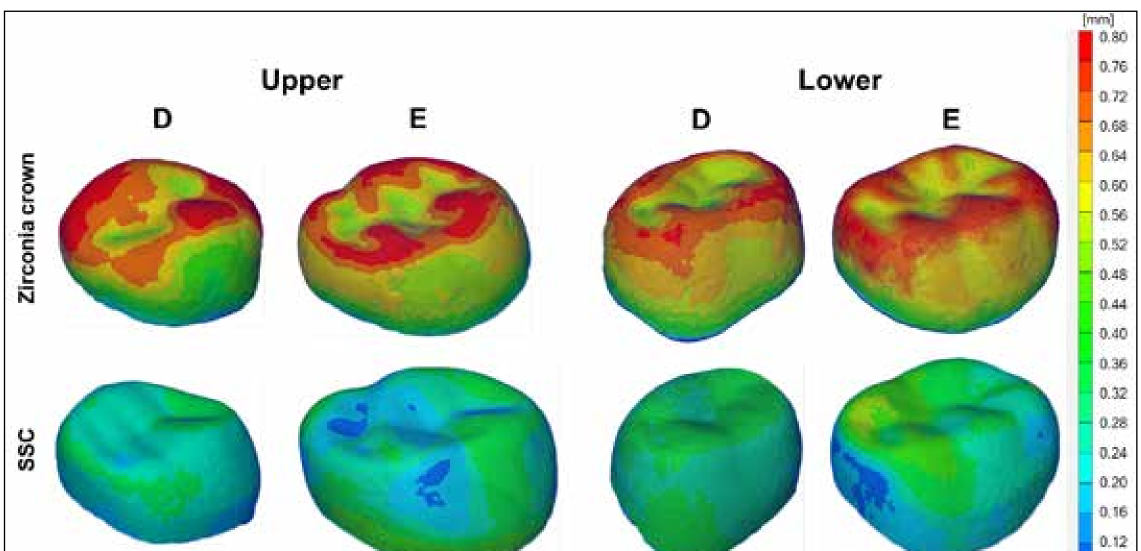


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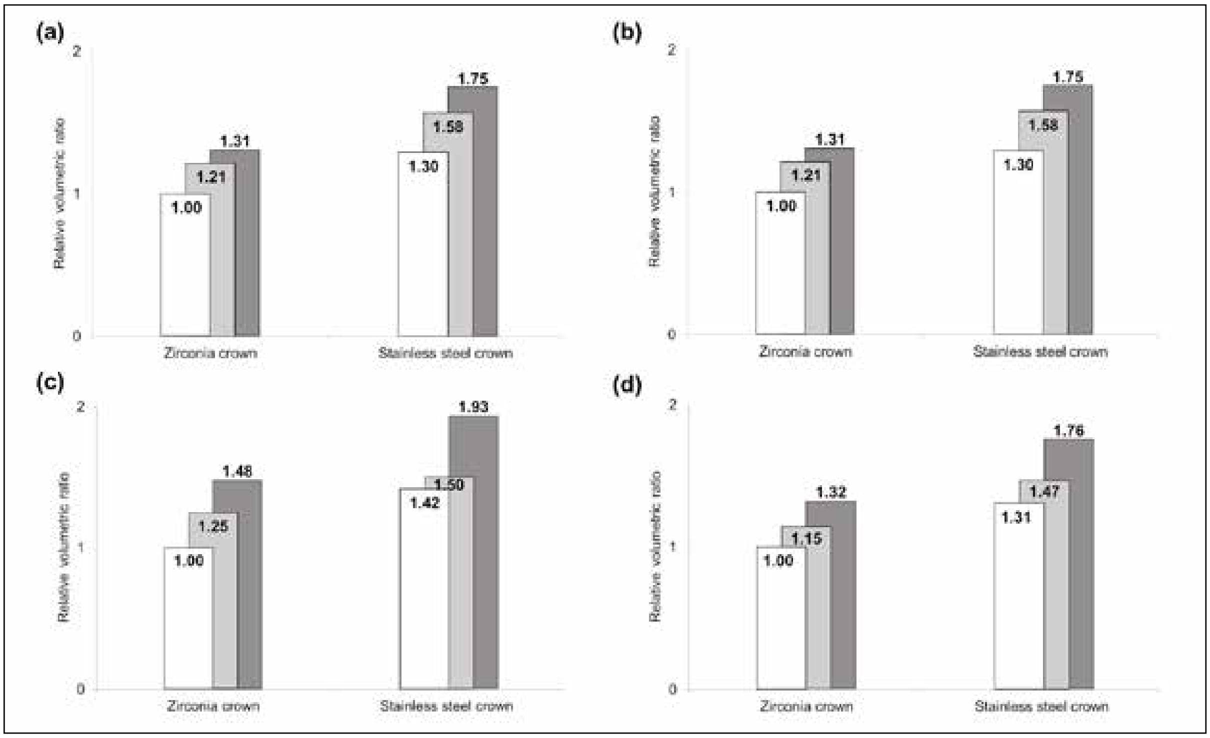
Figure 8. The relative volumetric ratio. Relative volumetric ratio was calculated by actual volume of each crown size per the actual volume of the smallest size of prefabricated zirconia crown. (a) relative volumetric ratio of upper primary first molar, (b) relative volumetric ratio of upper primary second molar, (c) relative volumetric ratio of lower primary first molar, (d) relative volumetric ratio of lower primary second molar.



DISCUSSION

As the esthetic demands of pediatric patients and their parents increase, prefabricated zirconia crowns are promising candidates for full-coverage restoration in pediatric patients. However, such crowns require more careful handling than SSCs; prefabricated zirconia crowns lack flexibility and cannot be crimped. Thus, tooth preparation is demanding.[7] When comparing the amounts of tooth reduction required to place crowns in pediatric patients, evaluations of inner surface dimensions should be performed in two types of crowns with same outer surface dimensions. In the present study, we measured both the inner and outer surfaces of two types of crowns; all surface dimensions differed. Although the outer surface MD diameters were similar, the BL diameters and heights differed. Therefore, it was impossible to compare the required tooth reductions of two types of crowns using this method.

Regarding the mechanical tolerance, there were mechanical tolerances in both crowns, it was considered as very small amounts. Thus, we believe that the influence of mechanical tolerance on crown dimension is not significant. Therefore, we verified that there is consistency among the specific crowns.

An ideal crown restoration should be in harmony with the opposing and adjacent teeth, featuring appropriate occlusal/proximal contacts. As both prefabricated zirconia crowns and SSCs should feature identical contacts, discrepancies between the outer and inner surfaces reflect different inner surface morphologies, aiding tooth preparation prior to crown placement. Notably, the 3D superimposition data revealed marked differences between the two crown types regardless of crown size. For SSCs, the discrepancy between the outer and inner surfaces was approximately 0.2 mm regardless of the chosen reference point. For pediatric zirconia crowns, the discrepancy varied by the reference point, being greatest at the cusp tip followed by the axial wall, fossa, and gingival margin. The present study also found that prefabricated zirconia crowns required more tooth reduction than SSCs: 3- to 4-fold more occlusal reduction, approximately 3-fold more axial wall reduction, and 1- to 2-fold more gingival marginal reduction.

Previous literatures have provided insufficient data to determine the difference of tooth reductions required between prefabricated zirconia crowns and SSCs. However, comparison of actual volumetric data between two types of crowns was realized in the present study. Prefabricated zirconia crowns needed larger amounts of reduction than SSCs and it was in accordance with the previous study.[7] The differences between two types of crowns appear to be caused by variation in the manufacturing parameters.

The manufacturers of the NuSmile ZR crown provide tooth preparation guidelines on their website, recommending a 1–2 mm reduction of the occlusal surface, following the natural contour; a 0.5–1.25 mm circumferential reduction; and finally, a feather edge of approximately 1–2 mm subgingivally.[11] In the present study, pediatric zirconia crowns required 0.6–0.8 mm of occlusal surface reduction, 0.6–0.8 mm of axial wall circumferential reduction, and 0.2–0.4 mm of cervical reduction (Figure 6). This difference may be related to space for the cement. The smaller cement space affords mechanical advantages.[12,13] However, such minimal tooth reduction is not clinically feasible, given the thickness of crowns. The cement space appropriate for a prefabricated zirconia crown remains unclear, but may be about 0.2 mm; a 0.2 mm internal occlusal gap has been observed in previous studies.[12,14,15] However, an additional space of 0.2–0.3 mm is required for clinical convenience, and indeed, this may vary with the clinical situation.

Considering the factors mentioned above, a 1.3 mm reduction of the cusp and a 1.1 mm reduction on the fossa would be more rational than the manufacturer's recommendations. The MD distance is always considered when a crown is selected. Thus, preparation of the interproximal area should extend for about 1 mm, because the thickness of the prefabricated zirconia crown at the contact area is up to 0.8 mm. The amounts of buccal and lingual reductions should be based on the status of the abutment teeth. The BL distance at the inner surface of the prefabricated zirconia crown (Table 1) could be a useful guide for the preparation of the BL wall.

The present study had certain limitations. There was lack of considerations about the differences in the subgingival margins required by each crown. When dental practitioners place SSCs, they usually trim the inferior margin of the crowns to an appropriate length prior to placement. However, only non-trimmed SSCs were included in the present study. In addition, the recommended subgingival margin depths differ for the two crowns, being approximately 1 mm for SSCs and approximately 2 mm for prefabricated zirconia crowns.[1,11] This may compromise comparisons between the gingival marginal areas and axial walls of the two types of crowns.

CONCLUSIONS

Posterior prefabricated zirconia crowns require careful tooth preparation. Greater amounts of tooth reduction are required than when placing posterior SSCs. Within the limits of the present study, more occlusal surface reduction than axial surface/gingival margin reduction was required when placing pediatric zirconia crowns. The measured data of inner surface of the crown would be useful when preparing tooth for the prefabricated zirconia crown.

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