Submitted: 14 December, 2022 Accepted: 24 March, 2023 Published: 03 September, 2023 DOI:10.22514/jocpd.2023.053

Journal of Clinical Pediatric Dentistry

ORIGINAL RESEARCH

Optimal post height and diameter in preformed zirconia crown restoration on 3D-printed primary incisors

Jong-Sung Kim[1,†], Gi-Min Kim[1,†], Hyun-Jung Kim[1], Jae-Sik Lee[1,*]

[1] Department of Pediatric Dentistry, School of Dentistry, Kyungpook National University, 41940 Daegu, Republic of Korea

***Correspondence**
leejs@knu.ac.kr
(Jae-Sik Lee)

[†] These authors contributed equally.

Abstract

In this *in vitro* study, fracture resistance was evaluated according to the post-diameter and -length in zirconia crown restorations on three-dimensional printed primary incisors undergone pulpectomy. One hundred-and-sixty primary incisor abutments were used which were artificially fabricated through 3D-printing. Each group was divided into two subgroups based on the zirconia post-diameter (1.5 mm and 2.0 mm) employed for post setting after pulpectomy. Furthermore, each group was divided into four subgroups based on the zirconia post-height (3.0, 4.0, 5.0 and 6.0 mm). Zirconia post setting was made by applying flowable resin after filling the pulp cavity with calcium hydroxide up to 3.0 mm below cemento-enamel junction (CEJ). Finally, a preformed zirconia crown of size #1 was cemented to the abutment through resin cement. A compressive load was applied to the middle palatal surface of incisors restored with zirconia crowns by using a universal testing machine at 145° angle which is the normal interincisal angle of children. The root fracture specimens were excluded and the samples fractured within crown and core parts were included in the final fracture resistance analysis. The group with 1.5-mm post-diameter and 5.0-mm post-height had the highest fracture resistance strength (130.63 $\pm$ 55.75 N) under masticatory pressure condition. Fracture resistance was statistically greater in 5.0-mm than in 4.0-mm and 3.0-mm post-height groups for 1.5-mm post-diameter subgroup. Moreover, 5.0-mm post-height subgroup had a statistically greater fracture resistance than that of 3.0-mm post-height subgroup for 2.0-mm post-diameter group. The 2.0-mm post-diameter subgroup had a statistically greater fracture resistance than that of 1.5-mm post-diameter subgroup for 3.0-mm and 4.0-mm post-heights. If zirconia post incorporation is required for deciduous incisor restoration, a post-length equal to facial CEJ level is recommended for gaining additional retention against masticatory pressure.

Keywords

3D-printing; Fracture resistance; Zirconia crown; Zirconia post-setting

1. Introduction

Primary anterior teeth are frequently encountered with crown damage in pediatric dental clinics because of early childhood caries (ECC) or trauma [1]. ECC is a rapidly progressing type of dental caries primarily in the cervical third of maxillary incisors causing up to full crown damage. It principally affects the primary maxillary incisors shortly following the teeth eruption and then rapidly infects other primary teeth, causing early tooth loss [2].

The restorative treatments of anterior primary teeth have been a challenge in pediatric dentistry. Numerous esthetic approaches are being employed for the restoration of structurally weakened primary teeth. Intracoronal tooth-colored restorations are made with materials such as resin-modified glass ionomers (RMGI), compomers, or resin composites [3]. Full-coronal esthetic restorations are accomplished with resin composite strip crowns [4], ready-made crowns, such as pre-veneered stainless-steel crowns [5], and recently introduced prefabricated primary zirconia crowns [6].

Zirconia crowns were presented in 2008 as an alternate restorative treatment [7]. Zirconia has history of being a biocompatible material. One of the advantages of zirconia crowns is their esthetic appearance and durability [8, 9]. Moreover, zirconia crowns show lesser plaque accumulation than the other materials because of highly polished surfaces [10, 11]. Furthermore, zirconia has excellent mechanical characteristics. Its flexural strength reaches up to 1200 MPa, and toughness up to 10 MPa [12, 13]. Zirconia crowns have three times higher strength compared to porcelain-fused-to-metal crowns [12, 13].

When there are severe carious defects in crown structure, the additional retention and stability to restoration is provided by post following pulp treatment of intra-canal space. However, gaining intra-canal retention in primary teeth through posts is complicated as permanent teeth need space to replace their primary counterparts [14]. Intra-canal posts thus be shed timely for the unimpeded eruption of permanent successors in normal undeflected positions [15]. Other requirements for the intra-canal posts in primary teeth are biocompatibility, ease of availability, applicability, esthetics, and withstanding masticatory forces [15].

Meyenberg *et al*. [16], introduced zirconia posts by reporting that their flexural strengths (900–1200 MPa) were comparable to cast gold or titanium, and also achieved the same post dimensions. With the development of computer-aided design and computer-aided manufacturing (CAD-CAM), zirconia post-and-core are developed as an alternate of cast post-and-core in esthetic zone [17–19]. Currently, zirconia posts are popular as they depict optical properties for post/cores like those of all-ceramic crowns [20].

Multiple studies regarding post and core systems are published, however, there is limited information pertaining to the fracture resistance as per zirconia post-length and diameter for the maxillary primary incisors undergone pulpectomy and zirconia crown restorations.

Purpose of this *in vitro* study was thus to evaluate the fracture resistance according to post-height and diameter on primary incisors treated with pulpectomy and zirconia crown restoration using 3D-printing.

2. Materials and methods

2.1 Preparation of specimens

2.1.1 Tooth selection

The maxillary right central incisor extracted because of the pulp necrosis was used in this *in vitro* study. The outer and internal canal structures of extracted incisors were scanned by micro-computed tomography (micro-CT) scanner (SKYSCAN 1272, Bruker, Billerica, MA, USA) (Fig. 1).

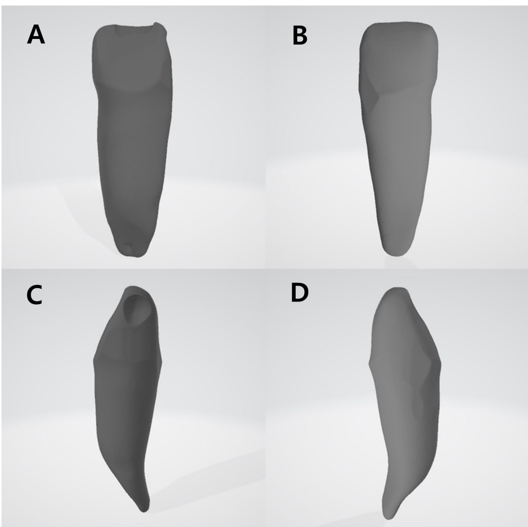

FIGURE 1. Micro-computed tomographic scanned images of extracted maxillary incisor. (A) Labial side view. (B) Palatal side view. (C) Distal side view. (D) Mesial side view.

2.1.2 Preformed zirconia crown selection

A preformed size #1 maxillary right zirconia crown of the most suitable size for the extracted incisor was also scanned by micro-CT (Fig. 2).

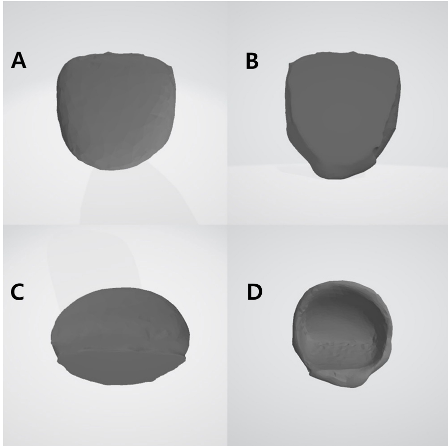

FIGURE 2. Micro-computed tomographic scanned images of size #1 upper right zirconia crown. (A) Labial side view. (B) Palatal side view. (C) Occlusal view. (D) Bottom view.

2.1.3 Superimposition of extracted incisor and zirconia crown images

The extracted primary maxillary incisor and zirconia crown images were overlapped using digital modeling (Fig. 3). Overlapping parts between the two images were deleted. A further 1.0-mm space was deleted for providing the cementation space. The access cavity was modeled based on the pulp cavity maximum value in the cross-section.

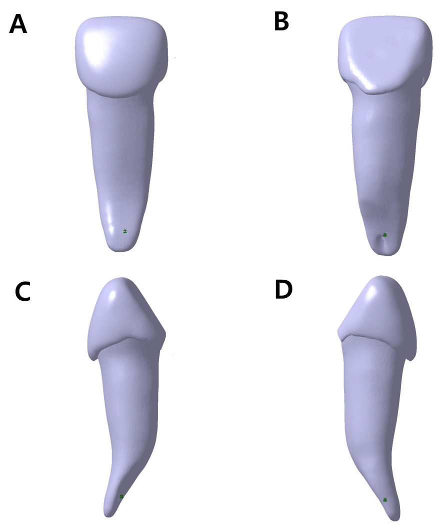

FIGURE 3. Superimposed images of extracted incisor and zirconia crown created through digital modeling. (A) Labial side view. (B) Palatal side view. (C) Distal side view. (D) Mesial side view.

2.1.4 Three-dimensional print of tooth models (3D-print)

One hundred-and-sixty (160) teeth were 3D-printed using resin materials (CROWNTEC, NextDent, Soesterberg, The Netherlands) as modeled abutment teeth. The crown surfaces of 3D-printed tooth models were sandblasted to properly adhere zirconia with tooth surfaces.

Subsequently, the 3D-printed incisors were embedded into self-cured acrylic resin (Vertex, Dentimex, Zeist, The Netherlands) just 1.0 mm above the cemento-enamel junction (CEJ).

2.2 Study group designs

The experimental groups were divided into two groups based on the prefabricated zirconia post-diameter: Group A (1.5-mm post-diameter) and Group B (2.0-mm post-diameter). The groups were further categorized into four subgroups depending on zirconia post-height: Group I (3.0-mm post-height), Group II (4.0-mm post-height), Group III (5.0-mm post-height), and Group IV (6.0-mm post-height) (Fig. 4).

There were eight groups with different post-diameter and -length combination (Table 1). Each group was assigned 20 tooth specimens. Thus, 160 specimens were utilized in this *in vitro* study.

2.3 Pulp treatment

The root canal was filled with $Ca(OH)_2$ (Vitapex, Neo Dental Chemical Products Co., Tokyo, Japan) up to 3.0 mm below the CEJ. Subsequently, the base materials (IRM, Dentsply Sirona, Tulsa, OK, USA) were filled to 1.0-mm thickness over the canal filling materials. This step indicated the general pulpectomy treatment of primary tooth.

2.4 Fiber post setting

Chamber preparation for an appropriate thickness of zirconia crown was made using #330 high-speed bur to set the prefabricated zirconia posts in intra-canal space. The fiber posts were fitted to chamber space according to the post-diameters (1.5 mm and 2.0 mm) and lengths (3.0 mm, 4.0 mm, 5.0 mm and 6.0 mm) based on respective group division.

2.5 Zirconia crown setting

The right maxillary incisor zirconia crown (NuSimle ZR, NuSmile, Houston, TX, USA) of size #1 was fitted to each tooth specimen. The optimal fitness between crown and tooth abutment was determined followed by the cementation with dure-cured resin cement (RelyX^{TM} Ultimate, 3M ESPE, Seefeld, Germany). Polishing was carried out after removing the excessive cement around zirconia crown and tooth surface (Fig. 5).

2.6 Fracture resistance analysis

Instron 3366 Universal Testing Machine (Instron, Norwood, CA, USA) was employed for evaluating the fracture resistance. Samples were fixed onto the machine at 145° to represent the normal interincisal angle in primary dentition (Fig. 6) [21].

A compressive load at crosshead speed of 1.0 mm/min was applied to the middle palatal surface of incisors restored with

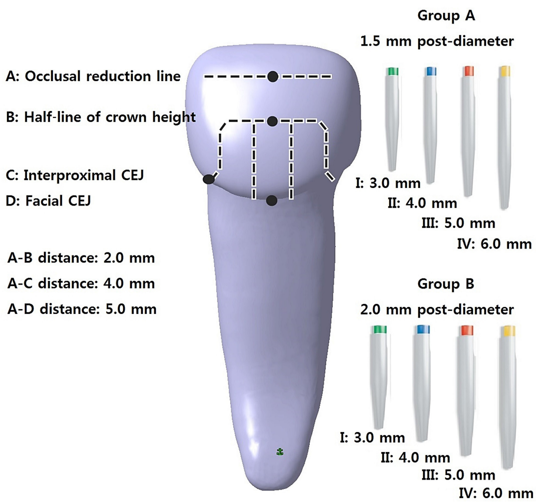

FIGURE 4. Experimental study groups determined according to prefabricated zirconia post-diameter and -length. (A) Occlusal reduction line. (B) Half-line of crown height. (C) Interproximal cementoenamel joint (CEJ). (D) Facial CEJ joint.

TABLE 1. Experimental groups.

Group	I (Length 3.0 mm)	II (Length 4.0 mm)	III (Length 5.0 mm)	IV (Length 6.0 mm)
A (Diameter 1.5 mm)	Group A I n = 20	Group A II n = 20	Group A III n = 20	Group A IV n = 20
B (Diameter 2.0 mm)	Group B I n = 20	Group B II n = 20	Group B III n = 20	Group B IV n = 20

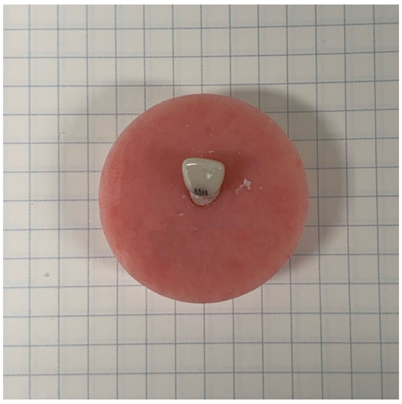

FIGURE 5. A completed experimental specimen.

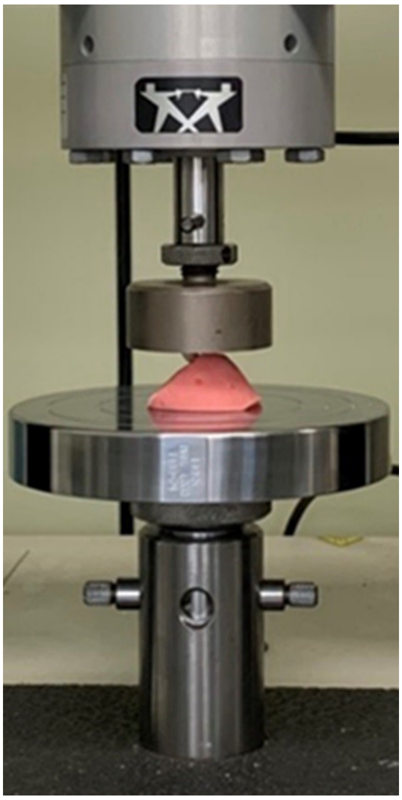

FIGURE 6. Instron rod was installed on palatal tooth surface at 145° angle to the long axis of tooth.

zirconia crown. The maximum compressive load was recorded at which the zirconia restoration got fractured or detached.

Fracture pattern analysis was made to verify the fracture pattern of each specimen after fracturing them by machine. Root fracture samples were excluded from the final analysis as they were not related to the retention of crown area. The final study included only the samples separated between zirconia crown and abutment interface, or between the post and tooth interface (Fig. 7). The number of samples included in the final study from group A were 8, 14, 14 and 10 for subgroups I, II, III and IV, respectively, and 12, 16, 14 and 10 for subgroups I, II, III and IV, respectively from group B.

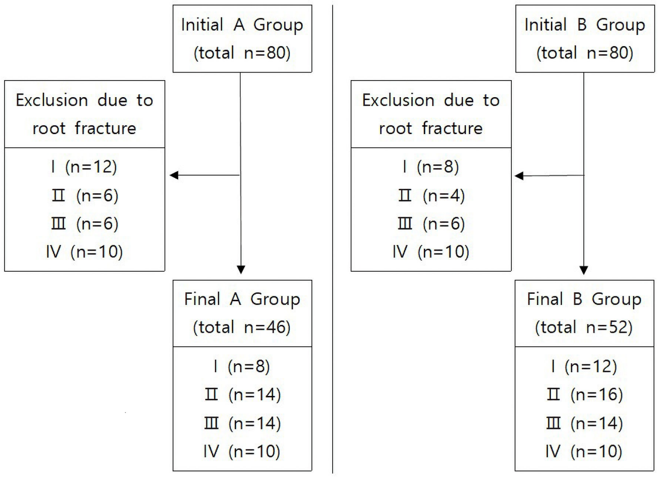

FIGURE 7. Flow diagram of the final samples' selection.

2.7 Statistical analysis

The results were analyzed using statistical software (SPSS version 25.0, IBM SPSS, Armonk, NY, USA). Mann-Whitney U test was conducted for analyzing the statistical significance of differences in fracture strength of fiber post-diameters. A one-way analysis of variance (ANOVA) test was executed to analyze the effect and statistical significance according to the fiber post-length, and Tukey honestly significant difference test as a *post hoc* test.

3. Results

3.1 Comparison of fracture resistance

The fracture resistance of zirconia crown restorations through pulpectomy and zirconia post setting according to post-diameter and -length are presented in Table 2 and Fig. 8. In 1.5-mm diameter subgroups, the fracture resistance to masticatory pressure was the highest for 5.0-mm post-height group (130.63 ± 55.75 N), followed by 6.0-mm post-height group (100.55 ± 42.62 N) and 3.0-mm post-height group (63.46 ± 8.82 N), and was the lowest for 4.0-mm post-height group (62.31 ± 28.19 N). In contrast, in 2.0-mm diameter subgroups, fracture resistance to masticatory pressure was the highest for 5.0-mm post-height group (128.48 ± 19.76 N), followed by 6.0-mm post-height group (120.53 ± 19.47 N) and 4.0-mm post-height group (101.39 ± 29.70 N), and was the lowest for 3.0-mm post-height group (78.80 ± 12.17 N).

3.2 Comparison of fracture resistance between groups

3.2.1 Comparison according to zirconia post-length

Fracture resistance exhibited significant differences between 3.0-m and 5.0-mm, and between 4.0-mm and 5.0-mm post-length groups for the 1.5-mm diameter group. Moreover, there was significant difference between 3.0-mm and 5.0-mm post-length groups for 2.0-mm diameter group (Table 3 and 4).

TABLE 2. Means and standard deviations of fracture resistance by zirconia post-diameter and -length.

Group	n (number)	Mean ± SD of fracture resistance (N)
A I	8	63.46 ± 8.82
A II	14	62.31 ± 28.19
A III	14	130.63 ± 55.75
A IV	10	100.55 ± 42.62
B I	12	78.80 ± 12.17
B II	16	101.39 ± 29.70
B III	14	128.48 ± 19.76
B IV	10	120.53 ± 19.47

A: 1.5-mm post-diameter, B: 2.0-mm post-diameter, I: 3.0-mm post-length, II: 4.0-mm post-length, III: 5.0-mm post-length, IV: 5.0-mm post-length, SD: standard deviation.

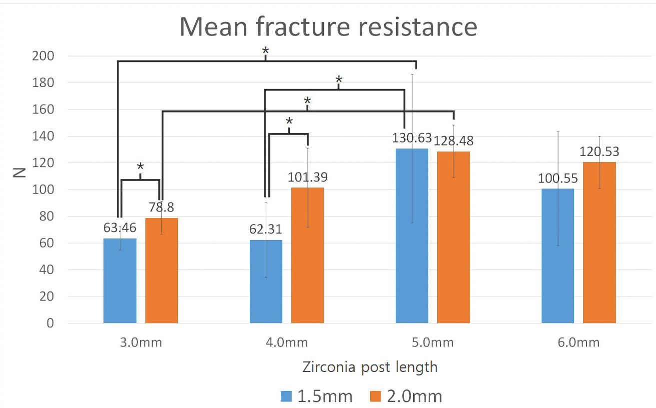

FIGURE 8. Means and standard deviations of fracture resistance by zirconia post-diameter and -length.

3.2.2 Comparison according to zirconia post-diameters

There were statistically significant differences in fracture resistance between 1.5-mm and 2.0-mm diameter groups for 3.0-mm and 4.0-mm post-length groups. However, no statistically significant difference was observed between 1.5-mm and 2.0-mm diameter groups for the post-lengths of 5.0 mm and 6.0 mm (Table 5).

4. Discussion

Primarily, this study was aimed to compare the fracture resistance of 3D-printed deciduous incisors restored with posts of two diameters and four lengths. The prefabricated zirconia post-lengths had differences between 3.0-mm and 5.0-mm post-length and between 4.0-mm and 5.0-mm post-length groups in 1.5-mm diameter group. The 3.0-mm and 5.0-mm post-length groups in 2.0-mm diameter group also had the difference. Regarding zirconia post-diameter, 2.0-mm group had statistically greater fracture resistance than 1.5-mm group for post-lengths of 3.0 mm and 4.0 mm, which were relatively the shorter post-lengths. However, the zirconia post-diameters for longer post-lengths had no statistically significant difference.

TABLE 3. Comparison of fracture resistance between zirconia post-lengths in 1.5-mm diameter groups.

Group	A I	A II	A III	A IV
A I	-	-	-	-
A II	1	-	-	-
A III	0.030*	0.010*	-	-
A IV	0.224	0.174	0.283	-

p value from Tukey HSD test ($p^* < 0.05$).
A: 1.5-mm diameter, I: 3.0-mm post-length, II: 4.0-mm post-length, III: 5.0-mm post-length, IV: 6.0-mm post-length.

TABLE 4. Comparison of fracture resistance between zirconia post-lengths in 2.0-mm diameter group.

Group	B I	B II	B III	B IV
B I	-	-	-	-
B II	0.082	-	-	-
B III	0.000*	0.018	-	-
B IV	0.021	0.738	0.384	-

p value from Tukey HSD test ($p^* < 0.05$).
A: 2.0-mm diameter, I: 3.0-mm post-length, II: 4.0-mm post-length, III: 5.0-mm post-length, IV: 6.0-mm post-length.

TABLE 5. Comparison of fracture resistance between zirconia post-diameters.

Group	A I	A II	A III	A IV
B I	0.026*	-	-	-
B II	-	0.010*	-	-
B III	-	-	0.490	-
B IV	-	-	-	0.323

p value from Mann-Whitney test ($p^* < 0.05$).
A: 1.5 mm diameter, B: 2.0 mm diameter, I: 3.0 mm length, II: 4.0 mm length, III: 5.0 mm length, IV: 5.0 mm length.

The fracture resistance of endodontically treated teeth was affected by various factors. A review analyzed factors affecting the fracture resistance of post-core reconstructed teeth which included post length, diameter, material, adaptability, design, amount of remaining dentin, cement, and biocompatibility of post material [22]. Another review on ferrule effect and biomechanical stability of teeth restored with cores, posts, and crowns revealed that the ferrule tooth structure was the most vital factor that resisted fracture and reduced forces compared to post, core, cement or resin bond materials [23]. In our results, the ferrule structure stability differed based on the length and diameter of zirconia posts because factors like crown type, residual tooth structure, and cement type were controlled.

A ferrule effect is described as a 360° metal collar of the crown surrounding parallel walls of dentine extending coronally to the shoulder of preparation [24]. The results reflect increase in the resistance because of the extension of dentinal tooth structure [25]. More specifically, the dentin parallel walls extending coronally from crown margin provide a "ferrule," which gives protection after being encircled by the crown and reduces stress within the tooth, termed as "ferrule effect" [26]. The prognosis of endodontically treated teeth has been given attention, and the ferrule effect is believed to stabilize such restored teeth [27–30]. A previous *in vitro* study depicted that the ferrule presence is important for improving fracture resistance in all-ceramic post and core systems [31].

In this study, the fracture resistance of maxillary primary incisors against masticatory load was the highest when zirconia post length reached 5.0 mm, *i.e.*, equal to the crown length. This could be attributed to the condition, when post reached facial CEJ (the lowest point of CEJ curvature), it ensured full integration of zirconia crown, the remaining tooth, and the post. Ferrule effect was maximized when post-length was equal to the crown-length. There was no statistically significant difference between 5.0-mm and 6.0-mm post-length subgroups, and added fracture resistance to masticatory pressure was not achieved when zirconia post-length was longer than that of facial CEJ.

Regarding extension of the post in primary tooth root canal, insertions of short retentive posts are required for the physiological resorption [32]. The intra-canal placement should be around 3 mm which characterizes the cervical one-third of the canal. It should not interfere with the deciduous tooth root resorption or permanent tooth eruption [32]. Both 5.00-mm and 6.0-mm post-length groups produced ferrule effect and met post-insertion conditions in primary dentition, however 5.00-mm group sufficed these requirements in better way than 6.00-mm group. Therefore, post-insertion equal to the crown length in primary incisors yields enough fracture resistance and allows physiological root resorption and natural eruption of subsequent permanent incisor.

As per this study results, 1.5-mm group was limited when post-length was 4.0 mm and fracture resistance of maxillary deciduous incisors was lower than that of 5.0-mm post-length. When post-length reached interdental CEJ which was the highest point of CEJ curvature, this was a condition where zirconia crown, the remaining teeth, and zirconia posts were only partially integrated. In summary, significant retention and ferrule effects against masticatory loads were achieved when zirconia post-length reached facial CEJ.

These results showed similar experimental tendency as found in previous *in vitro* study evaluating the fracture resistance according to glass-fiber post-length. Adanir *et al.* [33] reported different results based on clinical crown length. Higher fracture resistance was observed for the group having fiber posts of same length as that of clinical crown (9.0 mm), compared to the group with short fiber post-length (6.0 mm). However, no statistically significant difference was observed between fiber post-length group of 9.0 mm and 12.0 mm, exceeding clinical crown length. Adanir *et al.* [33] reported increased stress accumulation in cervical labial area when post-length was shorter than the clinical crown length.

Regarding prefabricated zirconia post-diameter, 2.0-mm post-diameter group had greater fracture resistance than 1.5-mm group for 3.0-mm and 4.0-mm post-lengths. In case of shorter zirconia post-length, the wider zirconia post may have more stability against masticatory load compared to narrower post. For short ceramic posts, it can be explained that posts of sufficiently thick diameter are required to densely fill the chamber space of primary incisor. Another *in vitro* study compared the fracture resistance of prefabricated zirconia posts of different diameters and surface treatments wherein the load to fracture for zirconia posts depended primarily on the post-diameter [34].

There was no statistically significant difference between 1.5 mm and 2.0 mm groups for post-lengths $\geq$5.0 mm. Zirconia post-length may be more important than post-diameter for achieving proper intra-canal retention with long zirconia post, especially those exceeding the crown length. Moreover, vertical factor can be more vital than horizontal for the post in acquiring sufficient ferrule effect. Pertaining to the effect of root region on retentive strength, Kurtz *et al.* [35] reported that bond strengths of posts in crown section were higher than in any other root region. Therefore, pediatric dental physicians must consider post-length rather than diameter when treating severely decayed deciduous incisors through pulpectomy and post incorporation followed by the zirconia crown restoration.

There are disadvantages of zirconia as post material despite the advances made in zirconia post and core systems. The higher rigidity of zirconia posts can be a predisposing factor for vertical root fractures [36]. Therefore, zirconia is not indicated for the patients in need of bruxism management. Moreover, it is almost impossible to retreat teeth restored with zirconia posts as it is too difficult to grind away the zirconia post and remove it from root canal [36]. Considering the re-treatment difficulty and subsequent permanent teeth eruption, the pediatric dental physicians must be aware of precautions for vertical extension of zirconia posts when placing them.

Masticatory loads are important for the fracture resistance of restored endodontically treated teeth. A previous study analyzed the bite force in children with primary dentition and depicted that the mean bite force in front anterior region (M = 49.58 ± 29.50 N) was lower than in posterior regions [37]. In posterior regions, the right side had slightly higher mean maximum bite force (M = 179.74 ± 72.15 N) than the left side (M = 175.07 ± 66.90 N) [37]. The mean fracture resistance for all specimens of present study was higher than the maximum physiological loads tolerated by the anterior teeth in oral environment. However, the fatigue pressure because of constant application of lower forces can cause tooth or restoration fractures.

The 3D-printing as an advanced manufacturing technology was employed in this *in vitro* study. It is based on CAD digital models using standardized materials to create personalized 3D objects through specific automatic processes [38–40]. 3D-printing in dentistry has wide applications in creating new and efficient dental products [41]. The 3D-printing and CAD software based on 3D imaging and modeling can produce complex geometric shapes of diverse materials [41].

To restrain the confounding factors such as bonding area linked to tooth size, the experimental specimens have been unified by three-dimensionally printing the abutments for this study. Resultantly, the retention of zirconia post system as per the post-length and -width could be evaluated through physio-mechanical approaches. The appropriate zirconia post-diameter and -length in zirconia post and crown restoration cases were achieved for managing the ECC cases frequently encountered in pediatric dentistry.

Nevertheless, there were certain limitations in this *in vitro* study. As the 3D-printed tooth specimen was made of resin material, the characteristics of prefabricated deciduous incisor teeth can be different from those of real deciduous incisor teeth. Compared to real primary incisors, the resin teeth can have different stiffness against compressive load or adhesion affinity to resin cement. More *in vitro* studies are imperative to develop a research design more closely representing the clinical conditions such as using actual deciduous teeth materials and thermocycling of final restoration.

5. Conclusions

Results of this study reveal that the incorporation of a post into intra-canal of maxillary incisor provides additional fracture resistance to zirconia crown restorations. Setting the zirconia post-length equal to facial CEJ level is recommended for maximizing the ferrule effect when treating maxillary anterior incisors through root canal procedure and zirconia post incorporation in pediatric dental clinics.

AVAILABILITY OF DATA AND MATERIALS

Not applicable.

AUTHOR CONTRIBUTIONS

JSL—designed the research study. JSK—performed the research. GMK—analyzed the data. JSK, GMK, HJK and JSL—wrote the manuscript. All authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not applicable.

ACKNOWLEDGMENT

Not applicable.

FUNDING

This research was financially supported by the Basic Science Research Program through National Research Foundation of Korea (NRF) funded by the Ministry of Education (2020R1G1A1010773).

CONFLICT OF INTEREST

The authors declare no conflict of interest.

REFERENCES

[1] Ferreira MC, Kummer TR, Vieira RS, Calvo MC. Short resin-posts bonding to primary dentin. Microleakage and micro-morphological *in vitro* study. Journal of Clinical Pediatric Dentistry. 2007; 31: 202–206.

[2] Rajesh R, Baroudi K, Reddy KB, Praveen BH, Kumar VS, Amit S. Modified anchor shaped post core design for primary anterior teeth. Case Reports in Dentistry, 2014; 2014: 306910.

[3] Lee JK. Restoration of primary anterior teeth: review of the literature. Pediatric Dentistry. 2002; 24: 506–510.

[4] Mendes FM, De Benedetto MS, del Conte Zardetto CG, Wanderley MT, Correa MS. Resin composite restoration in primary anterior teeth using short-post technique and strip crowns: a case report. Quintessence International. 2004; 35: 689–692.

[5] Usha M, Deepak V, Venkat S, Gargi M. Treatment of severely mutilated incisors: a challenge to the pedodontist. Journal of Indian Society of Pedodontics and Preventive Dentistry. 2007; 25: S34–S36.

[6] Walia T, Salami AA, Bashiri R, Hamoodi OM, Rashid F. A randomised controlled trial of three aesthetic full-coronal restorations in primary maxillary teeth. European Journal of Paediatric Dentistry. 2014; 15: 113–118.

[7] Ashima G, Sarabjot KB, Gauba K, Mittal HC. Zirconia crowns for rehabilitation of decayed primary incisors: an esthetic alternative. Journal of Clinical Pediatric Dentistry. 2014; 39: 18–22.

[8] Planells del Pozo P, Fuks A. Zirconia crowns—an esthetic and resistant restorative alternative for ECC affected primary teeth. Journal of Clinical Pediatric Dentistry. 2014; 38: 193–195.

[9] Aboushelib MN, Kleverlaan CJ, Feilzer AJ. Microtensile bond strength of different components of core veneered all-ceramic restorations. Part II: zirconia veneering ceramics. Dental Materials. 2006; 22: 857–863.

[10] Taran PK, Kaya MS. A comparison of periodontal health in primary molars restored with prefabricated stainless steel and zirconia crowns. Pediatric Dentistry. 2018; 40: 334–339.

[11] Abdulhadi B, Abdullah M, Alaki S, Alamoudi N, Attar M. Clinical evaluation between zirconia crowns and stainless steel crowns in primary molars teeth. Journal of Pediatric Dentistry. 2017; 5: 21.

[12] D'Addazio G, Santilli M, Rollo ML, Cardelli P, Rexhepi I, Murmura G, *et al*. Fracture resistance of zirconia-reinforced lithium silicate ceramic crowns cemented with conventional or adhesive systems: an *in vitro* study. Materials. 2020; 13: 2012.

[13] Pjetursson BE, Sailer I, Zwahlen M, Hämmerle CHF. A systematic review of the survival and complication rates of all-ceramic and metal-ceramic reconstructions after an observation period of at least 3 years. Part I: single crowns. Clinical Oral Implants Research. 2007; 18: 73–85.

[14] El-Shaabany MH, Mahfouz Omer SM, El-Baz GAE. Efficacy of different dentin posts for the treatment of primary anterior teeth (an *in vitro* study). Dental Science Updates. 2021; 2: 155–163.

[15] Mittal N, Bhatia HP, Haider K. Methods of intracanal reinforcement in primary anterior teeth—assessing the outcomes through a systematic literature review. International Journal of Clinical Pediatric Dentistry. 2015; 8: 48–54.

[16] Meyenberg KH, Lüthy H, Schärer P. Zirconia posts: a new all-ceramic

concept for nonvital abutment teeth. Journal of Esthetic and Restorative Dentistry. 1995; 7: 73–80.

[17] Awad MA, Marghalani TY. Fabrication of a custom-made ceramic post and core using CAD-CAM technology. The Journal of Prosthetic Dentistry. 2007; 98: 161–162.

[18] Streacker AB, Geissberger M. The milled ceramic post and core: a functional and esthetic alternative. The Journal of Prosthetic Dentistry. 2007; 98: 486–487.

[19] Bittner N, Hill T, Randi A. Evaluation of a one-piece milled zirconia post and core with different post-and-core systems: an *in vitro* study. The Journal of Prosthetic Dentistry. 2010; 103: 369–379.

[20] Nandini VV, Venkatesh VK, Kandaswamy D. Zirconia post-pressed ceramic core-supported all-ceramic crown: case reports and 4-year follow-up. The Journal of Indian Prosthodontic Society. 2007; 7: 199–202.

[21] Choi H, Kim J, Yoo SE, Kwon J, Park K. Cephalometric characteristics of Korean children with class III malocclusion in the deciduous dentition. The Angle Orthodontist. 2010; 80: 86–90.

[22] Fernandes AS, Dessai GS. Factors affecting the fracture resistance of post-core reconstructed teeth: a review. The International Journal of Prosthodontics. 2001; 14: 355–363.

[23] Mamoun JS. On the ferrule effect and the biomechanical stability of teeth restored with cores, posts, and crowns. European Journal of Dentistry. 2014; 8: 281–286.

[24] Juloski J, Radovic I, Goracci C, Vulicevic ZR, Ferrari M. Ferrule effect: a literature review. Journal of Endodontics. 2012; 38: 11–19.

[25] Sorensen JA, Engelman MJ. Ferrule design and fracture resistance of endodontically treated teeth. The Journal of Prosthetic Dentistry. 1990; 63: 529–536.

[26] Stankiewicz N, Wilson P. The ferrule effect. Dental Update. 2008; 35: 222–228.

[27] Slutzky-Goldberg I, Slutzky H, Gorfil C, Smidt A. Restoration of endodontically treated teeth review and treatment recommendations. International Journal of Dentistry. 2009; 2009: 1–9.

[28] Khaled AL-Omiri M, Mahmoud AA, Rayyan MR, Abu-Hammad O. Fracture resistance of teeth restored with post-retained restorations: an overview. Journal of Endodontics. 2010; 36: 1439–1449.

[29] McLean A. Predictably restoring endodontically treated teeth. Journal—Canadian Dental Association. 1998, 64: 782–787.

[30] Morgano SM. Restoration of pulpless teeth: application of traditional principles in present and future contexts. The Journal of Prosthetic Dentistry. 1996; 75: 375–380.

[31] Zhang YX, Zhang WH, Lu ZY, Wang KL. Fracture strength of custom-fabricated Celay all-ceramic post and core restored endodontically treated teeth. Chinese Medical Journal. 2006; 119: 1815–1820.

[32] Shah S, Bargale S, Anuradha KVR, Patel N. Posts in primary teeth-a sile for better smile. Journal of Advanced Medical and Dental Sciences Research. 2016; 4: 58–64.

[33] Adanir N, Belli S. Evaluation of different post lengths' effect on fracture resistance of a glass fiber post system. European Journal of Dentistry. 2008; 2: 23–28.

[34] Oblak C, Jevnikar P, Kosmac T, Funduk N, Marion L. Fracture resistance and reliability of new zirconia posts. The Journal of Prosthetic Dentistry. 2004; 91: 342–348.

[35] Kurtz JS, Perdigão J, Geraldeli S, Hodges JS, Bowles WR. Bond strengths of tooth-colored posts, effect of sealer, dentin adhesive, and root region. American Journal of Dentistry. 2003; 16: 31A–36A.

[36] ÖZKURT Z, ISERI U, KAZAZOGLU E. Zirconia ceramic post systems: a literature review and a case report. Dental Materials Journal. 2010; 29: 233–245.

[37] Mountain G, Wood D, Toumba J. Bite force measurement in children with primary dentition. International Journal of Paediatric Dentistry. 2011; 21: 112–118.

[38] Vukicevic M, Mosadegh B, Min JK, Little SH. Cardiac 3D printing and its future directions. JACC: Cardiovascular Imaging. 2017; 10: 171–184.

[39] Lin L, Fang Y, Liao Y, Chen G, Gao C, Zhu P. 3D printing and digital processing techniques in dentistry: a review of literature. Advanced Engineering Materials. 2019; 21: 1801013.

[40] Alharbi N, Alharbi S, Cuijpers VMJI, Osman RB, Wismeijer D. Three-dimensional evaluation of marginal and internal fit of 3D-printed interim restorations fabricated on different finish line designs. Journal of Prosthodontic Research. 2018; 62: 218–226.

[41] Tian Y, Chen C, Xu X, Wang J, Hou X, Li K, *et al*. A review of 3D printing in dentistry: technologies, affecting factors, and applications. Scanning. 2021; 2021: 1–19.

How to cite this article: Jong-Sung Kim, Gi-Min Kim, Hyun-Jung Kim, Jae-Sik Lee. Optimal post height and diameter in preformed zirconia crown restoration on 3D-printed primary incisors. Journal of Clinical Pediatric Dentistry. 2023; 47(5): 57-64. doi: 10.22514/jocpd.2023.053.