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Original article

Comparative evaluation of stress generation in primary teeth restored with zirconia and BioFlx crowns: A finite element analysis

Sayali Deolikar[1], Nilesh Rathi[1], Vini Mehta[2]
[1]Department of Pediatric and Preventive Dentistry, Dr. D. Y. Patil Dental College and Hospital, Dr. D.Y. Patil Vidyapeeth, Pune 411018, India
[2]Department of Dental Research Cell, Dr. D. Y. Patil Dental College and Hospital, Dr. D.Y. Patil Vidyapeeth, Pune 411018, India

ABSTRACT

Background: *Maintaining the functional integrity of primary teeth is important, as these teeth are integral in vital functions such as mastication, speech development, and space maintenance for permanent teeth; hence, premature loss of primary teeth can affect a child's quality of life. Various restorative materials are available to restore the function of grossly decayed teeth. Stainless steel crowns and zirconia crowns are widely used in pediatric dentistry; however, there are certain disadvantages associated with these materials. Recently introduced BioFlx crowns provide acceptable esthetics with a conservative approach. Nevertheless, there is a lack of evidence regarding their strength and clinical acceptability. Finite element analysis measures the physical response of teeth and assesses the stress generation, which is important to estimate the integrity of the restorations and crowns.* ***Purpose:*** *The aim of this in vitro study was to evaluate and compare stress generation in primary teeth restored with zirconia and BioFlx crowns using finite element analysis.* ***Methods:*** *Models of extracted teeth restored with zirconia and BioFlx crowns were used for the study. The finite element analysis of these models was carried out through Analysis of Systems (ANSYS) software. The models were subjected to a simulated occlusal loading force of 245 N.* ***Results:*** *Von Mises stress generated in BioFlx crowns along with underlying dentin was much less compared to that which was generated in zirconia crowns.* ***Conclusion:*** *Restoring the functional integrity of carious teeth is essential. BioFlx crowns can be used as full coverage restorations and can be a suitable alternative to zirconia crowns and traditional stainless steel crowns.*

Keywords: *BioFlx; deformation; finite element analysis; stress generation; zirconia*
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Correspondence: Vini Mehta, Department of Dental Research Cell, Dr. D. Y. Patil Dental College and Hospital, Dr. D. Y. Patil Vidyapeeth, Pune, Maharashtra 411018, India. Email: vini.mehta@statsense.in

INTRODUCTION

With the current global increase in the prevalence of dental caries in children and their effect on a child's quality of life, it is important to maintain the functional activity and integrity of the primary dentition.[1] Primary teeth are possibly the best space maintainers, as they help preserve the integrity of the arch length and width and the appropriate space for the permanent teeth. Various restorative procedures are carried out for carious lesion management and certain developmental tooth defects to maintain and preserve the functional integrity of the primary dentition.[1] However, these restorative procedures require some amount of carious lesion excavation and removal of a certain amount of tooth structure, especially in cases that require endodontic therapy due to total pulp loss. This results in the weakening of the structural integrity and integral strength of the tooth.[2,3]

Reinforcing weakened teeth with various restorative materials or extracoronal restoration is necessary so they may better withstand masticatory forces.[4] Restorative materials such as glass ionomer cement (GIC), resin-modified glass ionomers, resin-filled composites, amalgam, and crowns, such as stainless steel and zirconia crowns, are used for restoring such teeth.[5,6] Stainless steel crowns are conventionally considered the preferred and accepted treatment modality for teeth with multi-surface carious lesions and those endodontically treated, but they have

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certain limitations with respect to acceptable esthetics. Presently, in consideration of the different restorative treatment modalities, some of the primary and paramount concerns are factors such as the material's biocompatibility and its esthetic acceptability among patients.[6]

With superior esthetics and better mechanical properties, the zirconia crown has been introduced to the field as a restorative treatment material for primary and permanent teeth. It is also enriched with many important and useful properties, such as subsequent dimensional stability, superior biocompatibility, and being metal-free and completely bioinert. However, tooth preparation for zirconia is much more extensive and aggressive when compared to materials such as conventional stainless steel crowns. This results in the weakening of the involved tooth, which may lead to decoronation of the tooth and failure of the respective crown under masticatory load.[2,7,8] Recently introduced to the field, BioFlx crowns were developed to provide esthetics with a conservative approach regarding tooth preparation. Compared to stainless steel crowns, they are more esthetically pleasing, and tooth preparation is more conservative compared to zirconia crowns. Finite element analysis (FEA) investigates the generation of stress in the tooth and its prosthesis. The stress analysis' utilization of the FEA model is useful for stipulating the physical response of the structure and the entire system, such as fracture-prone areas and surfaces of the teeth.[8,9] Many studies have been done on the FEA of different crowns, but no studies have been conducted on the FEA of BioFlx crowns. Therefore, the aim of this study was to evaluate and compare stress generation in primary teeth restored with zirconia crowns and BioFlx crowns using FEA.[10,11]

MATERIALS AND METHODS

This study is approved by the Institutional Ethical Committee with reference number DYPDCH/DPU/EC/465/91/2022. This in an in vitro study. The study utilized two models of extracted primary maxillary second molars. The selected extracted teeth were required to fit specific criteria, which included teeth with an intact crown and the same amount of tooth structure. One tooth was restored with a zirconia crown and another tooth with a BioFlx crown. Both teeth were then subjected to FEA. An assessment was completed of the stress generation in the crown as well as the entire body of the tooth. The study procedure was carried out in three steps, starting with the model preparation of the extracted primary maxillary second molars with zirconia and BioFlx crowns, respectively. This was followed by the generation of the finite element model using Analysis of Systems (ANSYS) software. In the final step, the application of calculated lateral and perpendicular forces on the model was completed. Stress generation and deformation in the models were calculated.

Extracted primary second molar teeth were collected from the Department of Pediatric and Preventive Dentistry in accordance with the study requirements and criteria. Both specimens of the teeth were prepared by embedding the teeth in custom-made acrylic molds. They were equally divided into two groups: zirconia crowns and BioFlx crowns. The teeth were prepared by a solo operator to abolish inter-operator bias. The preparation was performed using TF-21 and FO-32 carbide burs. For the zirconia crowns, tooth preparation was done according to the manufacturing guidelines of Kids-e-Dental (Mumbai, Maharashtra). For the BioFlx crowns, the preparation was done according to the manufacturer instructions provided by NuSmile (Houston, U.S.A). As per the study's requirements, a sequential circumferential tooth reduction was done evenly, such that the entire enamel, along with most of the dentin, was reduced. After tooth preparation, 25%–30% of the dentin was left. This was done in order to resemble a severely destructed tooth. The zirconia crowns and BioFlx crowns were luted with GIC.

The prepared models of primary second molars were scanned. Three-dimensional images of these prepared models were obtained through computed tomography scans, and stereolithography (STL) files of the models were created. The ANSYS software was used for the FEA of these STL files. The software transformed 0.5 mm sections of each model individually into cloud data points. This assembly was used to create a mesh work. After the mesh work was created, it was used to obtain the surface model of each prepared model.

Lateral and perpendicular forces of 245 N were applied to both the files of zirconia crown and BioFlx crown models. This was done to replicate physiological masticatory forces. The perpendicular forces were applied on the outer inclines of the palatal cusp and the inner inclines of the buccal cusps and palatal cusp. Lateral masticatory forces were applied at 0°, 45°, and 90°. They were applied through angulated forces on the inner inclines of the buccal cusps at the mesial pit, distal pit, central pit, and oblique ridge. These specific sites were selected because they reproduce maximum occlusal forces in patients of the pediatric age group. The stress generation values and created patterns due to the perpendicular and lateral load applications were calculated based on the von Mises dimensional criterion.

RESULTS

The stresses were visualized through color-coding that ranged from dark blue (minimum stress) to red (maximum stress). Stress generation (MPa) and deformation (mm) through perpendicular forces in the crown and on the crown and tooth for both the BioFlx and zirconia crowns were calculated. Figure 1 shows the FEA crown contours, stress generation, and deformation in the zirconia and BioFlx crowns.

Table 1 depicts the comparison between the zirconia and BioFlx crowns (perpendicular forces on the crowns). The stress generation in the zirconia crown was estimated

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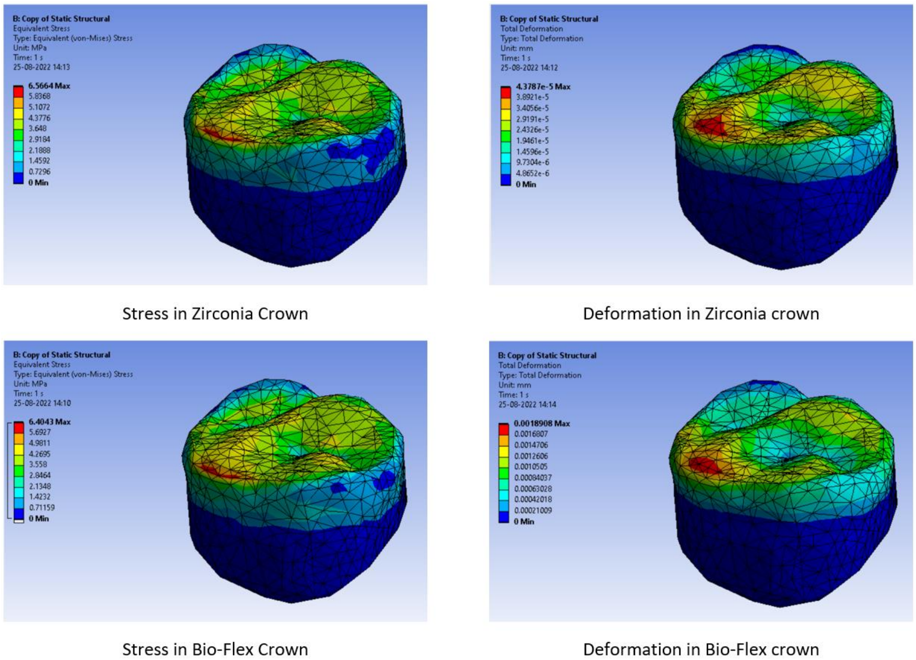

Figure 1. Finite element analysis crown contours.

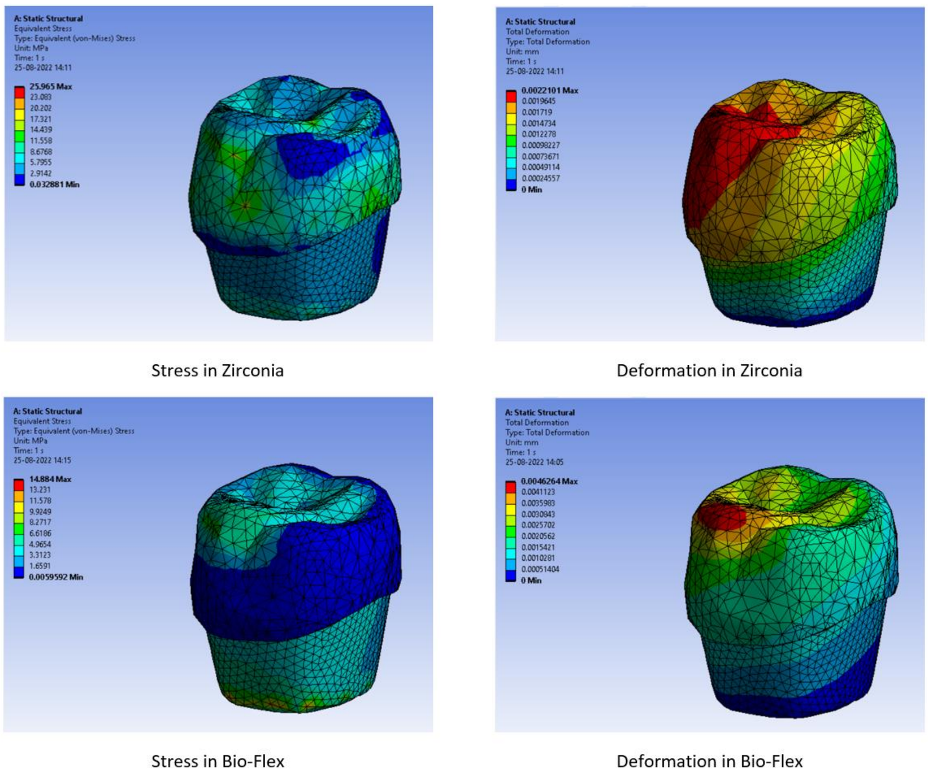

Figure 2. Finite element analysis crown and tooth contours.

Table 1. Comparison between zirconia crown and BioFlx crown (perpendicular forces)

Material	Perpendicular forces through crown		Perpendicular forces through dentin	
	Stresses (MPa)	Deformation (mm)	Stresses (MPa)	Deformation (mm)
Zirconia	6.5654	0.000043	25.965	0.00221
BioFlx	6.4043	0.001890	14.884	0.00462

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to be 6.5654 MPa. Stress generation in the BioFlx crown was estimated to be 6.4043 MPa. Deformation with the zirconia crown was 0.000043 mm. Deformation with the BioFlx crown was 0.001890 mm. Figure 2 highlights the FEA crown and tooth contours, showing stress generation and deformation through perpendicular forces in the crown and tooth. The stress generated in the zirconia crown was 25.96 MPa. The stress generated in the BioFlx crown was 6.4043 MPa. The measured deformation with the zirconia crown was 0.000043 mm, while deformation with the BioFlx crown was 0.001890 mm. Table 2 depicts the comparison between the zirconia crown and the BioFlx crown (lateral forces through the crown at 90°, 45°, and 0°). Figure 2 depicts the FEA crown and tooth contours; forces were applied on the crown at the mesial pit, central pit, distal pit, and oblique ridge.

Figure 3 depicts the locations of the pits and ridges. At 90°, the stress generated in the zirconia crown was 6.2206 MPa at the mesial pit, 4.6897 MPa at the central pit, 4.9359 MPa at the distal pit, and 7.2453 MPa at the oblique ridge. For the BioFlx crown, the stress generated was 3.1483 MPa at the mesial pit, 2.1614 MPa at the central pit, 3.0005 MPa

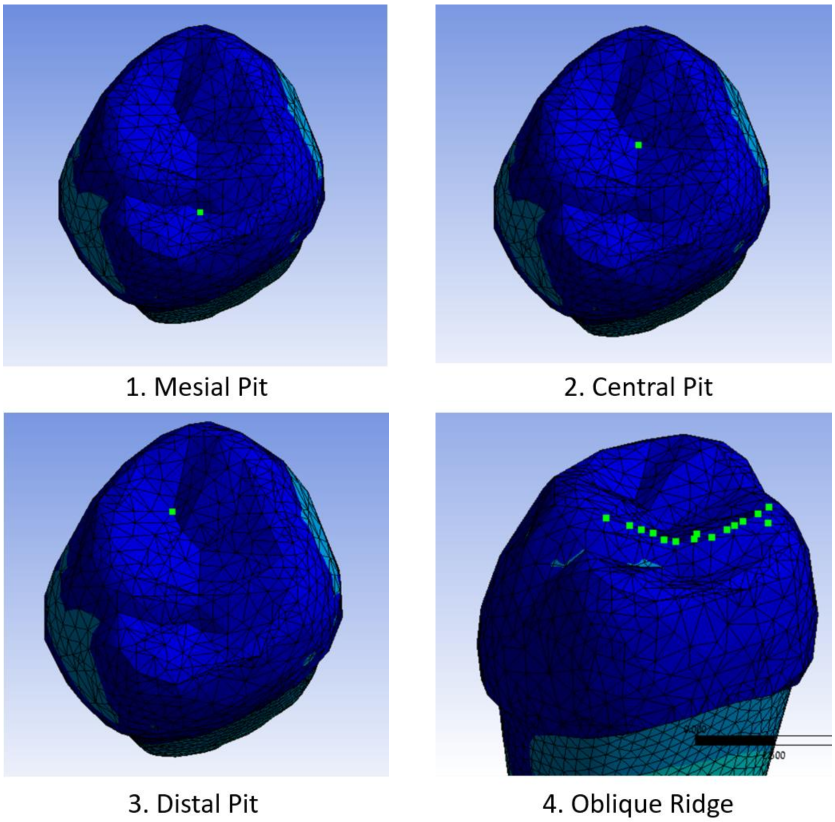

Figure 3. Locations of different pits and ridges.

Table 2. Comparison between zirconia crown and BioFlx crown (lateral forces)

Locations	Stresses (MPa)					
	Zirconia	BioFlx	Zirconia	BioFlx	Zirconia	BioFlx
	Forces at 90°		Forces at 45°		Forces at 0°	
Mesial pit	6.2206	3.1483	9.5106	6.8067	12.927	10.296
Central pit	4.6897	2.1614	11.606	8.0381	16.321	11.158
Distal pit	4.9359	3.0005	8.4944	7.6242	12.052	9.6218
Oblique ridge	7.2453	4.1094	8.4944	6.1464	8.3860	7.6179

Table 3. Stresses and deformation in whole body at different angle forces

Forces at different angles	Stresses (MPa)		Deformation (mm)	
	Zirconia	BioFlx	Zirconia	BioFlx
90°	25.965	14.884	0.0022	0.0046
45°	122.28	81.859	0.0177	0.0238
0°	169.02	103.38	0.0241	0.0316

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at the distal pit, and 4.1094 MPa at the oblique ridge. At 45°, the stress generated in the zirconia crown was 9.5106 MPa at the mesial pit, 11.606 MPa at the central pit, 8.4944 MPa at the distal pit, and 8.2441 MPa at the oblique ridge. For the BioFlx crown, the stress generated was 6.8067 MPa at the mesial pit, 8.0381 MPa at the central pit, 7.6242 MPa at the distal pit, and 6.1464 MPa at the oblique ridge. At 0°, the stress generated in the zirconia crown was 12.927 MPa at the mesial pit, 16.321 MPa at the central pit, 12.052 MPa at the distal pit, and 8.3860 MPa at the oblique ridge. For the BioFlx crown, the stress generated was 10.296 MPa at the mesial pit, 11.158 MPa at the central pit, 9.6218 MPa at the distal pit, and 7.6179 MPa at the oblique ridge.

Table 3 depicts stresses and deformation in the whole body at different angle forces. At 90°, the stress generated in the tooth restored with the zirconia crown was estimated to be 25.965 MPa, and the deformation was 0.0022 mm. The stress generation within the tooth restored with the BioFlx crown was 14.884 MPa. The deformation was estimated to be 0.0046 mm. At 45°, the stress generation in the tooth restored with the zirconia crown was estimated to be 122.28 MPa, and the deformation was 0.0177 mm. The stress generated within the tooth restored with the BioFlx crown was 81.859 MPa, and the deformation was 0.0238. At 0°, the stress generated in the tooth restored with the zirconia crown was 169.02 MPa, and the deformation was 0.0241 mm. The stress generated in the tooth restored with the BioFlx was 103.38 MPa, and the deformation was 0.0316 mm. The stress generated in the zirconia crown and underlying dentin was higher compared to the BioFlx crown on the application of perpendicular forces as well as the lateral forces at 90°, 45°, and 0°. The BioFlx crown showed a higher rate of deformation compared to the zirconia crown when subjected to the perpendicular and lateral forces.

DISCUSSION

Dental caries is an infectious process. It is the most common chronic disease in children.[1,12] It is a significant public health problem. With the increase in the prevalence of caries, it has become important to maintain the functional activity of the primary dentition by performing various restorative treatments.[1,2,13,14] Numerous completed studies and sufficient available literature demonstrate the efficacy of the stainless steel crown as an extracoronal restoration for primary teeth affected by severe caries, teeth that have undergone pulp therapy, and teeth used as an abutment for certain orthodontic interventions.[3,6] However, there is currently an increased demand with respect to the esthetics and the final outcome of restorative treatments.[2,7]

Originally introduce in 2008, zirconia crowns have recently gained popularity. Zirconia has proven to have many advantages, such as superior esthetics, excellent biocompatibility, and good dimensional stability and durability. It also has superior mechanical properties.[2,7] There is a better acceptance among parents who have esthetic demands, especially in cases where anterior teeth are severely compromised.[15] However, there are certain clinical drawbacks associated with the use of zirconia, such as the extensive tooth preparation for zirconia crowns, which requires aggressive tooth reduction; the cost is also comparatively high.[3,7,10]

New BioFlx crowns were introduced recently by NuSmile. These are biocompatible, high-strength, esthetic crowns. The advantages of BioFlx crowns are their flexibility, good adaptability, and active fit; additionally, the tooth preparation is similar to that of traditional stainless steel crowns, with slightly more occlusal reduction. As stated by the manufacturers, BioFlx meets the FDA requirements. However, the long-term durability of these crowns is important; their stress-bearing capacity and especially their ability to withstand masticatory forces should be assessed qualitatively and quantifiably, compared, and examined to justify their use in the clinical setting.[11,16,17] An FEA assesses stress propagation through the entire tooth structure as well as the restorative material.[17–19] It has the ability to reveal the stress-bearing areas through a manner in which the finite element model is prepared; the type of model created can be two- or three-dimensional.[20,21] There is a distinct way in which the mesh is constructed, and the system is structured in terms of the pressure, coercion, and loads.

Therefore, in this study, the stress generation was assessed for the zirconia and BioFlx crowns to demonstrate their capacity to withstand masticatory forces and occlusal load. It has been stated that, in the specific areas in which the tensile stress is greater, there is a higher possibility a fracture will occur.[6,9,15,22,23] Based on the previous studies conducted, it was taken into consideration that, for primary teeth, the masticatory forces are within the range of 161–330 N.[11,24–27] For the application on the stress-bearing areas, this study considered a mean force of 245 N to replicate physiologic masticatory forces. The application of loading forces was done with different angulations. Lateral and perpendicular forces of 245 N were applied to the crowns. As mentioned earlier, areas with high tensile stress were selected. Perpendicular forces were applied on the outer inclines of the palatal cusp and the inner inclines of the buccal cusps and palatal cusps. Lateral masticatory forces were applied at 0°, 45°, and 90° through angulated forces on the inner inclines of the buccal cusps at the mesial pit, distal pit, central pit, and oblique ridge. The stress generation due to masticatory forces were anticipated to be better appreciated in these areas.

In this study, the zirconia and BioFlx crowns were subjected to perpendicular forces through FEA. For the crown and tooth combined as a whole tooth structure and for only the crown, and ranging from minimum to maximum, the von Mises stress (MPa) in the BioFlx was much less compared to the zirconia crown. This suggests there is a lesser stress generation within the BioFlx crown and subsequently lesser propagation of stress through the crown on the underlying tooth and precisely the dentin. We have

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also assessed the deformation with both the crowns (mm). Deformation was seen more with BioFlx than zirconia, which suggests that BioFlx crowns are more flexible and possess a greater elasticity.

When the crowns were subjected to lateral forces at 0°, 45°, 90° on the mesial pit, distal pit, central pit, and oblique ridge, the stress generation was less in the BioFlx crown compared to the zirconia crown. The stresses were calculated in MPa. At 0° and 45°, the maximum stress generation in the zirconia crown is observed on the central pit, followed by the mesial and distal pits, and then the least is observed on the oblique ridge. At 90°, the maximum stress generation is observed on the oblique ridge, followed by mesial pit, then the distal and central pits. The stress generation in the BioFlx crown was much less than in the zirconia crown. Previous studies have compared the stress generation in different crowns and restorative material through a finite element model.[28,29] Prabhakar et al.[18] evaluated and compared an FEA stress analysis of primary teeth restored with zirconia and stainless steel crowns, and the authors concluded there was a lesser stress generation in zirconia crowns than stainless steel crowns, which suggests that the ability of the tooth restored with a zirconia crown to withstand masticatory forces is better.[2,3,30] These results are in accordance with the results of the present study, as the stress generation values in zirconia were comparable. However, in the present study, the stress generation under masticatory forces of various angulations is much less in the BioFlx crown than the zirconia crown. The BioFlx crowns' ability to withstand the masticatory forces when subjected to the load application from different angulations at different stress points is shown to be better compared to zirconia, which demonstrates the better flexibility of BioFlx crowns.

The deformation followed by the occlusal load application was also assessed in this study. It was observed that the deformation was greater with the BioFlx crown than the zirconia crown. Though this demonstrates their superior flexibility, it also suggests the possibility of early crown dislodgement. The study's results establish the necessity of a restorative material that should enable a grossly decayed, mutilated tooth or endodontically treated tooth to withstand a fracture as well as demonstrate the ability to protect the pulp. The FEA provides information regarding the exact stress generation within the respective material and also the propagation of the stress into the underlying dentin. Although materials like stainless steel have been considered the gold standard, with the changing era, there is an increased demand for a material that is esthetic with good dimensional stability. Zirconia has proven its superior esthetic and greater dimensional stability. However, the aggressive tooth preparation can be a limitation. BioFlx crowns can be used as an alternative, as the properties and mechanical preparation are comparable to stainless steel crowns, with the added benefit of an acceptable esthetic. There is a need to assess the BioFlx crown on the basis of biological parameters with an evidence-based approach to establish its efficacy in clinical settings. However, as this is an in vitro trial, the technical and software-associated errors can be considered the limitations of this trial.

In conclusion, BioFlx crowns have comparable esthetics and mechanical properties to conventional stainless steel crowns and zirconia crowns. The tooth preparation for BioFlx crowns is less aggressive compared to zirconia crowns. The results of the study suggest that, through FEA, the BioFlx crown was estimated to have a lower von Mises stress generation than the zirconia crown**.** Though both crowns were subjected to perpendicular and lateral forces, the BioFlx crown's capability to withstand these forces and resist crown fracture was greater, and the condition of the underlying tooth was better. As this is an in vitro trial, further clinical trials are recommended to assess the reliability of BioFlx crowns.

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