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COMPARATIVE EVALUATION OF A NORMAL PRIMARY CENTRAL INCISOR AND A PRIMARY CENTRAL INCISOR WITH ZIRCONIA CROWN WITH AND WITHOUT MOUTHGUARD USING FINITE ELEMENT ANALYSIS

Pedodontics

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ABSTRACT

Aim: the aim of this study was to evaluate the effect of impact stress on a primary central incisor with and without mouthguard and crown using finite element analysis. **Methodology:** Four 3 D FEA models of a normal primary central incisor and zirconia crown with and without 2mm EVA mouthguard were obtained from a cbct scan of a 3 year old child. Boundary conditions were defined . Impact analysis was carried out in Ansys inc software. **Results:** Results were obtained through Von mises analysis. In such analyses, color mapping about stress distribution is done. Normal primary maxillary central incisor without mouthguard and primary central incisor with zirconia crown reported higher stresses as compared to models with mouthguard. **Conclusion:** 2mm custom fitted EVA mouthguard is effective in mitigating impact stress in 3-5 year old children. Therefore, use of mouthguards should be encouraged in clinical practice even for pediatric patients .

KEYWORDS

Primary Dentition, Trauma, Finite Element Analysis

INTRODUCTION

The main cause of traumatic dental injuries in primary teeth are increased locomotor experiences of the children at different ages. The age of the child at the moment of the injury is an important factor for the development of sequelae in the permanent successors. The disturbances in enamel development are one of the most common types of sequelae to permanent successors.[1,2] To restore function and esthetics in a child and thereby enhance normal psychological development of child various artificial crowns are used in pediatric dentistry are polycarbonate crowns, strip crowns and newer crowns such as zirconia crowns.[3]

As it is rightly said that prevention is better than cure. Mouthguards have been used in dentistry to prevent trauma to the dentition. A mouthguard is defined as a resilient device or appliance placed inside the mouth to reduce oral injuries, particularly to teeth and surrounding structures. [4]

Finite element analysis is a powerful method to assess stress and strain distribution in teeth and materials under load application using mechanical properties of structures.[5,6] Since it is difficult to replicate a maxillofacial trauma in situ, FEA seems to be a pertinent method to identify the potential regions of structural failure during an impact. Therefore, the aim of this study is to evaluate the effect of impact stress on a primary central incisor with and without mouthguard and crown using finite element analysis.

METHODOLOGY

This study was conducted after the ethical approval by the institutional ethical board. The three-dimensional geometry of all the experimental elements were obtained from a three-dimensional Cone Beam Computed Tomography (CBCT) scan of 3-year-old child reporting to the Department of Pediatric And Preventive Dentistry at Seema Dental College And Hospital, Rishikesh suspected of trauma in primary maxillary anterior teeth.

The acquired CBCT images were then processed to create a three-dimensional model. This modeling task was accomplished using Fusion 360, a software product developed by Autodesk Inc. and SolidWorks software, developed by Dassault Systèmes SolidWorks Corporation. This 3D model aimed to represent the anatomical structures and features of the teeth and periodontium based on the information extracted from the CBCT scan.

The normal primary maxillary central incisor was modeled with a crown length of 6mm, root of 10 mm length with a mesiodistal width of 6.5mm incisally and 4.5mm cervically. The labiolingual dimensions were 5mm and 4.5 mm at the cervix of the crown.

Following this tooth preparation was done for the zirconia crown where 1mm labial and lingual preparation outlines and 1.5 mm incisal, 0.5-0.75 mm proximal preparation were defined. The margin was feather edge which was placed 2 mm sub gingivally. This was followed by creating the mouthguard of 2 mm thickness in both the models and 4 finite element models were generated which were

- Finite Element Model 1- Normal tooth (Fig 1)
- Finite Element Model 2- Tooth with zirconia crown (Fig 2)
- Finite Element Model 3- Normal tooth with a mouthguard (2 mm Thickness) (Fig 3)
- Finite Element Model 4- Tooth with zirconia crown and mouthguard (Fig 4)

Fig 1. Finite Element Model 1

Fig 2. Finite Element Model 2

Fig 3 Finite Element Model 3

Fig 4. Finite Element Model 4

The material properties mentioned in Table 1 were applied to the respective finite element model to simulate structures of tooth and periodontium. Boundary conditions were established to replicate the constraints on the model and to restrict it from undergoing free body motion. The set boundary condition was same for all the models

Table 1: Material Properties Applied To The Finite Element Models To Simulate The Biomechanical Conditions.

Tissue	Modulus Of Elasticity (MPa)	Poisson's Ratio
Enamel	80350	0.33
Dentin	19890	0.31
Pulp	2	0.45
Periodontal ligament	50	0.45
Cancellous Bone	490	0.3
Cortical Bone	14700	0.3
Zirconia	200	0.31
EVA mouthguard	18075	0.30
GIC cement	0.4x104	0.3

The impact analysis was conducted utilizing ANSYS, Incsoftware. The analysis simulated a scenario where the incisor experiences a frontal impact against an immovable, rigid surface. In this simulation, the model moved horizontally towards the unyielding surface, starting with an initial velocity of 1 m/s; equivalent to 3.6 km/h for 0.005. Resultant impact was carried analyzed using Von mises analysis. Von-Mises stress is a type of equivalent stress that combines the three principal stresses (tensile, compressive, and shear) into a single value. It is used to predict yielding of materials under various loads.

The von-Mises stress σ_{VM} was calculated using the principal stresses $(\sigma_1, \sigma_2, \sigma_3)$

$$\sigma_{VM} = \sqrt{\frac{1}{2}\left[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2\right]}$$

This equation represented a circular yield criterion in the principal stress space, and the von-Mises stress was considered a conservative estimate for yielding. The reason it is widely used is that it simplifies the complex stress state into a single value, making it easier to assess whether a material will yield or not. This simplification is particularly valuable in the design and analysis of structures, where a quick determination of the safety of a design is essential.

In such analyses, color mapping is a common technique to quickly

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convey information about stress distribution. Red: Represents the maximum principal stresses. Orange, Yellow, Green: Successive colors represent decreasing stress levels. Blue: Represents the lowest level of stress.

RESULTS

Following results were drawn after performing Von Mises analysis for stress distribution.

In Model 1(Normal central incisor without a mouthguard), the overall stress on the tooth was considerably higher at 28.926 Mpa. Notably, the enamel experienced a stress of 10.015, and the dentin bared a stress of 7.1537. Additionally, the periodontal ligament (PDL) and cortical bone encountered stress levels of 0.0012745 and 5.7699, respectively. The cancellous bone, root, and pulp also exhibited stress values of 2.797, 5.4872, and 0.000436, respectively. (Fig 5)

In Model 2 (Primary Maxillary Central Incisor with a Zirconia Crown without a mouthguard) the overall stress on the tooth was relatively high at 43.828 Mpa. The enamel experienced a stress of 12.733, and the dentin bared a stress of 7.958. Other structures also exhibited stress levels, with the periodontal ligament (PDL) at 0.063094, cortical bone at 4.1421, cancellous bone at 25.157, root at 0.17193, and pulp at 0.0009707.(Fig 6)

On the other hand, in Model 3 (Normal central incisor with a mouthguard), the overall stress decreased significantly to 5.8689. The enamel stress was reduced to 3.0634, and the dentin stress dropped to 2.2977. The PDL and cortical bone experienced lower stresses of 0.000371 and 3.325, respectively. The cancellous bone, root and pulp also showed reduced stress levels at 2.2508, 0.000296 and 0.000114 respectively.(Fig 7)

In Model 4 (Primary Maxillary Central Incisor with a Zirconia Crown and a mouthguard) the overall stress decreased significantly to 5.8551 Mpa. The enamel stress was reduced to 2.1439, and the dentin stress dropped to 1.8376. The PDL and cortical bone experienced lower stresses of 0.00041516 and 4.6379, respectively. The cancellous bone, tooth, root, and pulp also showed reduced stress levels at 1.1377, 0.00033673, and 0.00039246, respectively. (Fig 8)

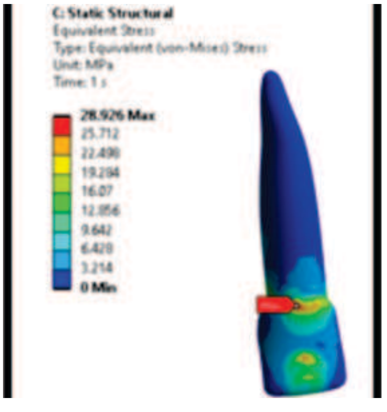

Fig 5. Stress Distribution through Von Misses analysis in Model 1

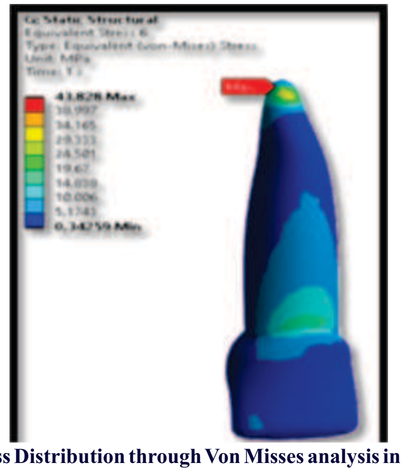

Fig 6. Stress Distribution through Von Misses analysis in Model 2

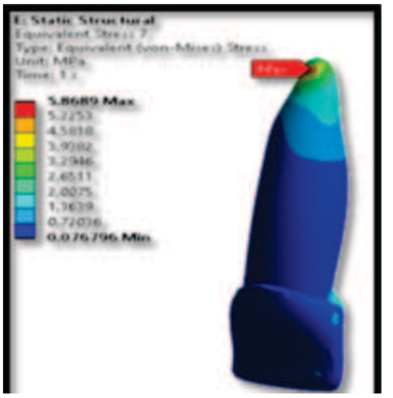

Fig 7. Stress Distribution through Von Misses analysis in Model 3

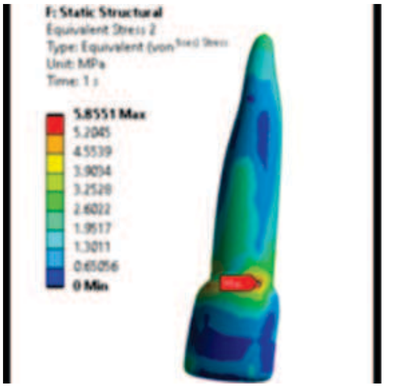

Fig 8. Stress Distribution through Von Misses analysis in Model 4

Table 1 On comparing Model 1 with the mouthguard to Model 3 without a mouthguard, the results indicated a substantial reduction in overall stress on the primary maxillary central incisor when the mouthguard was applied. The values provided represent stress distribution across different dental structures. (Table 2).

The comparison between Model 2 and Model 4 revealed a substantial difference in overall stress distribution across various dental structures. (Table 2).

Table 2: Von Misses Stress Distribution Amongst Various Structures In All Models.

Variable	Model 1- Primary Maxillary Central Incisor without a mouthguard	Model 2- Primary Maxillary Central Incisor with a Zirconia crown without a mouthguard	Model 3 - Primary Maxillary Central Incisor with a mouthguard	Model 4- Primary Maxillary Central Incisor with a Zirconia Crown and mouthguard
Overall Stress	28.926	43.828	5.8689	5.8551
Enamel	10.015	12.733	3.0634	2.1439
PDL	0.001275	0.063094	0.000371	0.00041516
Cortical Bone	5.7699	4.1421	3.325	4..6379
Cancellous Bone	2.797	25.157	2.2508	1.1377
Root	5.4872	0.17193	0.000296	0.00033673
Pulp	0.000436	0.0009707	0.000114	0.00039246
Dentin	7.1537	7.958	2.2977	1.8376

DISCUSSION

Ng L et al.[7] reported a higher prevalence of traumatic dental injuries (TDI) in children aged under 5 years (56.1%), predominantly among males (63.8%). Deciduous teeth constituted the majority (58.4%), with the maxillary central incisors being the most frequently injured (69.9%). Lateral luxation emerged as the predominant injury type, accounting for 27.5%.

Tiwari N et al. [8] and Govindranjan M et al. [9] identified a marginally increased prevalence of traumatic dental injuries (TDI) in children under 6 years and in the 3-6 age group, respectively.

Since extensive research has been documented in the literature concerning preventive measures for traumatic dental injuries (TDI) in children with mixed dentition, the present study specifically delved into the primary maxillary central incisor, shedding light on the intricacies of traumatic dental injuries in this specific dental context.

A mouthguard (MG) serves as a resilient intraoral device designed to mitigate oral injuries, with a primary focus on protecting teeth and adjacent structures. [10] Ethylene vinyl acetate (EVA) stands out as the predominant material employed in mouthguard fabrication .Renowned for its pliability and impact resistance, EVA ensures an optimal balance of comfort and protection. Its widespread use underscores its efficacy in absorbing and dispersing forces that may otherwise lead to dental trauma. [11,12] Verrisimo et al. [13] conducted an evaluation of tooth stresses, strains, shock absorption, and displacement during impact, focusing on custom-fitted ethylene vinyl acetate (EVA) mouthguards with varied thicknesses ranging from 2 to 6 mm.

Opting for scientific rigor, in the present study custom fitted ethylene vinyl acetate (EVA) mouthguard with a 2 mm thickness was selected. This deliberate choice was based on the nature of primary dentition and aimed to evaluate the efficacy of a thinner mouthguard in providing optimal protection.

The present study employed Finite Element Analysis to assess the impact stress on a primary central incisor, considering the influence of mouthguard and crowns. The investigation aimed to provide a comprehensive understanding of biomechanical responses to impact scenarios, evaluating the efficacy of protective measures.

In the present study, the Finite Element Method was employed to simulate traumatic frontal impact conditions on a primary maxillary central incisor. Diverging from recent FEA studies simulating free-moving steel or concrete structures with an incisor, our study focused on a distinct scenario. Specifically, an impact to the primary maxillary central incisor was simulated against a stationary rigid surface, akin to scenarios involving striking the ground during sporting activities or colliding with a solid structure. This approach enhances the applicability of our findings to real-world situations, providing valuable insights into the biomechanical responses of primary incisors under conditions mimicking common traumatic events.[13,14]

In the present study, distinct patterns of stress concentration within various dental structures under different conditions were observed. This phenomenon can be elucidated by the horizontal direction of impact, resulting in a compressive force on the labial tooth surface, juxtaposed with tensile stresses experienced by the palatal and cervical regions. Given that enamel possesses lower tensile strength compared to other dental structures, it emerges as a critical site prone to potential failure. In the present study it was revealed that the highest overall impact stress in models lacking a mouthguard was observed in the primary maxillary central incisor with the zirconia crown and the intact tooth. This aligns with findings by Gabrin CA et al.[15], where none of the assessed restorations successfully restored the stress distribution observed in the intact tooth. In the models with mouthguard Von misses stresses were highly reduced.This finding aligns with the results of a study conducted by Dal Piva AMo et al., [16] which demonstrated the advantageous effects of mouthguards in mitigating the impact of dental trauma, irrespective of the type of restorative material utilized in the fabrication of indirect veneers.

The study's limitations include the exclusion of the antagonist tooth and the entire maxillary arch, alongside the absence of measurements for lip and gingival coverage. Furthermore, the lack of comparative studies on mouthguards in primary dentition limited the breadth of analysis for result comparison.

CONCLUSION

The present study highlights the need for vigilance among children with primary dentition who have received esthetic rehabilitations following trauma or early childhood caries to mitigate potential harm, particularly to their remaining enamel structures. It reinforces the significance of 2mm EVA mouthguard utilization for the pediatric patients with and without prosthetic rehabilitation, as a means of minimizing dental injuries.

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