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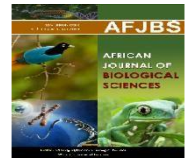

Research Paper Open Access

Assessing Fracture Resistance and Chewing Efficiency: Zirconia vs. Stainless Steel Crowns in Primary Molars

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Abstract:

Introduction:

The importance of preserving primary teeth until natural exfoliation necessitates simple, affordable dental restorations for children, typically lacking in cooperation. Stainless steel crowns are common but less aesthetically pleasing compared to tooth-colored options like zirconia, known for strength and biocompatibility. In vitro studies mimicking oral conditions through human saliva, chewing simulation, and thermocycling aid in understanding material durability and fracture resistance, crucial for clinical decision-making in pediatric dentistry

Materials And Methods:

This in-vitro study was done in a private college in Chennai. The study encompasses two different types of pre manufactured Zirconia crowns and one pre manufactured Stainless Steel Crowns, with a total of 12 samples in each group. Following the fabrication of the abutment, the crowns were affixed to the CoCr models using glass ionomer cement. The crown group was separated into three intervention groups: Group I acted as the control without any additional intervention, Group II underwent aging with human saliva, and Group III underwent 5 years of chewing and thermocycling after being first stored in a humid chamber at 37°C for 24 hours.

Results:

The study conducted an analysis on a total of 36 samples, which were organized into 3 groups consisting of 12 samples each. Each group was then further broken into subgroups, with each subgroup containing 4 samples, based on the different treatments applied. The fracture load of all samples was measured, and the survival of the crowns was also evaluated for the thermocycling and chewing stimulator groups. The study findings indicated that Nu-Smile crowns exhibited poorer fracture resistance in comparison to other brands. Specifically, 3M Stainless Steel crowns showed exceptional resilience, particularly during chewing stimulation. The results of the two-way ANOVA showed that both the intervention and brand had a significant impact on the fracture load. A post hoc study revealed significant distinctions between crown types and therapies. The Kaplan Meier study demonstrated a 50% survival rate for Nu-Smile crowns as a result of fatigue cracks, in contrast to a 100% survival rate for SS and Kedo zirconia crowns. This indicates a significant difference in crown survival ($P < 0.004$).

Conclusion:

The fracture loads of Kedo zirconia crowns were found to be similar to those of stainless steel, indicating their effectiveness in withstanding occlusal forces. This positions Kedo zirconia as a viable alternative to stainless steel, supporting the trend toward aesthetics in pediatric dental care.

Keywords:

Milk tooth, tooth coloured crown, hardness, silver crown, human saliva

Introduction:

Primary teeth are necessary for chewing and space maintenance and it is imperative that they be preserved until physiological exfoliation (1). Since children typically have minimal cooperation during treatment, dental restorations for primary teeth should be simple, affordable, and quick to complete (2) . When pulpotomy procedures result in significant deterioration, prefabricated stainless-steel crowns are frequently employed. However, due to the growing significance of aesthetics, parents and patients prefer tooth-colored crowns (3,4).

Two materials that stand out from the rest due to their unique qualities are zirconia and stainless steel, which have the potential to be strong competitors in the field of dental restorations. Because of its ceramic composition, zirconia is a striking material for applications like crowns and bridges because it combines mechanical strength, biocompatibility, and a natural look (5). In contrast, stainless steel is highly valued for its strong durability and resistance to corrosion, making it a well-established powerhouse in the dental field (6,7).

When it comes to temporary or permanent applications and pediatric patients in particular, stainless steel has shown to be a reliable material because to its exceptional strength and resistance to corrosion (8). Conversely, zirconia's superior mechanical characteristics, biocompatibility, and aesthetic appeal have made it more well-known. For both materials, there are advantages as well as disadvantages (9,10). Zirconia's resistance to fracture is the main factor limiting its application . Numerous in vitro experiments have demonstrated various characteristics of these materials. However, evidence-based clinical decision-making requires a thorough understanding of how these materials react to fracture load in the oral environment . To mimic the oral environment, there are 3 interventions that can be designed in an invitro study (11).

Human saliva, a complex biological fluid that exposes the crowns to the chemical and enzymatic milieu of the oral cavity, is the initial intervention. The second intervention is to simulate the mechanical stresses that occur during mastication by using a chewing stimulator. Lastly, thermocycling adds a thermal element to the research by modeling the natural cyclical temperature variations found in the oral cavity (12).

The choice to incorporate human saliva in the aging process stems from the understanding that the mouth environment is a dynamic ecosystem with a wide range of biochemical activities occurring there (13). Over time, saliva, a complex fluid that includes different proteins, electrolytes, and enzymes, may affect the material qualities of dental crowns (14).

The second intervention group, ageing by a chewing stimulator, seeks to simulate the mechanical obstacles encountered throughout the masticatory process. The long-term success of dental crowns depends on their capacity to tolerate the occlusal stresses that they are continuously subjected to, which might vary in intensity (15). Through the simulation of mechanical forces, the chewing stimulator facilitates a methodical and controlled evaluation of the fracture resistance of the crowns, providing important information on their mechanical resilience (16).

Thermocycling, the third intervention, adds a thermal component that mimics the typical fluctuations in temperature in the oral cavity. Over time, material fatigue and microcracks may result from the dental materials' cyclical expansion and contraction in reaction to temperature fluctuations (17). To the best of our knowledge, inadequate investigation has been done to evaluate the fracture load of pedo crowns in customized settings. The present study aimed to assess the fracture load and survival rate of pediatric stainless steel and zirconia crowns under designed invitro environment which mimics the oral cavity.

Materials and Methods:

Study setting and sample size calculation:

This in-vitro study was done in the white lab associated with the department of Pedodontics and preventive dentistry. This study was approved by the Institutional Ethics Committee. The sample size of the study was calculated to be 36 from the study done by Kist S et al, 2019 with power 95 and alpha error 5% (18).

Abutment preparation:

Tooth 75 (FDI notation) was manufactured in a phantom head in a dental training model (AK-6/2; Frasaco, Tettnang, Germany) in compliance with the manufacturer's instructions in the CAD/CAM group. Using a convergence angle of 3°, 0.8–1.2 mm of anatomical substance were removed circumferentially and 1–1.5 mm was removed occlusally to form a gingival chamfer. A silicone guide (inlay impression tray size M; SPEIKO, M€unster, Germany) and Optosil Comfort Putty und Activator Universal Plus Paste (Heraeus Kulzer, Hanau, Germany) were employed to analyze the tooth reduction. The preparations were duplicated using CAD/CAM technology to create cobalt-chromium (CoCr) abutments.

Using a five-axis milling device (ceramill motion 2; Amann Girrbach) and a ceramill database software version 1.0 (Amann Girrbach, Koblach, Austria), the preparations were milled out of CoCr blanks (Ceramill Sintron 71L 20 mm; Amann Girrbach). To enable the research, the abutments were machined and subsequently placed on sturdy resin cubes.

Study groups / Crown types:

The types of crowns and their brands (groups) and the overview of the study is given in Figure 1. There are two brands of prefabricated zirconia crowns and one brand of gold standard 3M Stainless Steel Crowns were included in the study with sample of 12 in each group. After the abutment was prepared, all the crowns were cemented on CoCr models with glass ionomer cement (Ketac Cem; 3M ESPE, Seefeld, Germany). After the cementation each group of crowns were subdivided into 3 groups with 4 samples in each intervention. One group did not undergo any further intervention and considered as the control group (Group I), Group II underwent aging under human saliva and Group III underwent 5 years of chewing and thermocycling following storage of crowns in a humid chamber for 24 h at 37°C.

Group II intervention:

Ten participants, aged between twenty and thirty, whose dental and overall health were in good condition, provided saliva samples. Saliva samples were obtained in the morning before meals, following stimulation (chewing on paraffin), and the volunteers were instructed not to clean their teeth for 24 hours prior to the sample collection. After that, the cemented crowns were kept for 12 weeks at 37°C in the combined saliva samples. Biweekly, the saliva was replaced. 1% HCl or 1% NaOH was used to maintain a consistent pH between pH 6.5 and pH 7.5.

Group III intervention:

The crown samples were mounted to the chewing stimulator using WhipMix Mounting Plaster (Ivoclar Vivadent AG, Schaan Fürstentum, Liechtenstein), a high-strength, low-expansion plaster that sets quickly. After the steatite opponents (Steatite, SD Mechatronik, Munich, Germany) were used to imitate enamel, the metal mounts were covered with acrylic resin. The steatite balls had dimensions of 4 mm for both length and diameter. They were kept just shy of fossa occlusion with the help of the zirconia and SS crowns. The chewing simulator has four test chambers (CS-4, SD Mechatronik, Munich, Germany) that were housed inside a thermocycling chamber. The horizontal table (X-axis) and the vertical bar (Z-axis) are their two moving components. The table had the samples fixed to it, and it could tilt back and forth. The antagonists moved vertically while attached to the vertical bar. The five kilogram weight load was used to apply masticating load by the antagonists

The vertical bar housed the antagonist samples, which had a diameter of 4 mm, while the horizontal bar supported the force sensors, allowing the force exerted at each cycle to be measured (Steatite, SD Mechatronik, Munich, Germany). A weight was added to each rod to increase the masticatory load on each sample, simulating the oral environment. Thermocycling was done in two cycles, one hot and one cold, and between 10 and 60 degrees Celsius. One half-minute at a time, the chamber was full. The quantity of cycles corresponds to clinical use during a roughly seven-year period. In this investigation, 1.68 x 10^6 chewing cycles were conducted in conjunction with simultaneous thermocycling.
Three times a day, the crowns were visually inspected during the chewing simulation procedure. A crown was considered to have failed if it had worn down, chipped veneer, cracked, had fatigue cracks, or had an occlusal surface hole. In the latter case, the failure to meet the survival rate analysis criteria was noted but the fracture load was not assessed.

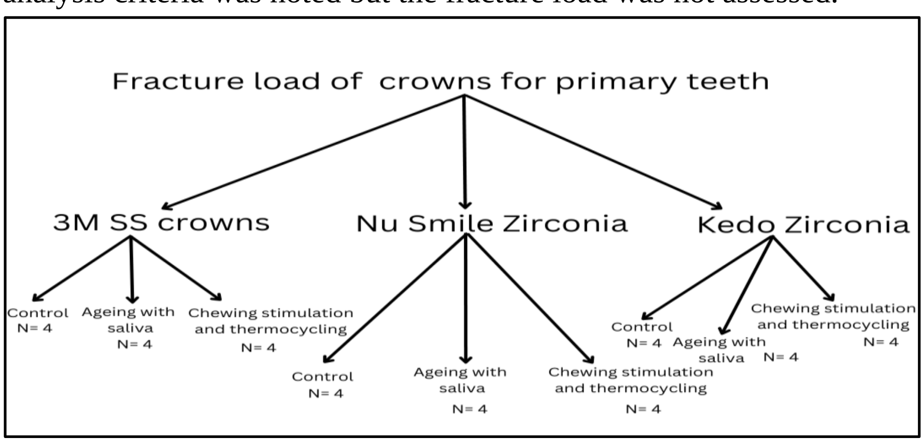

Figure 1: Overview of the study groups

Assessment of fracture load:

A universal testing machine (Instron5566, Instron Ltd., Buckinghamshire, UK) was used to put the crowns. The measurement was made with the punch (6 mm diameter) in the central fossa, perpendicular to the occlusal surface, and at a crosshead speed of 1 mm min 1. A piece of 0.5-mm-thick tinfoil (Dentaurum, Ispringen, Germany) was positioned between the loading jig and the occlusal sur face in order to prevent force peaks. The fracture load test was halted and the corresponding load was recorded as soon as crack development was noticed. Stainless-steel crowns were exempt from the fracture load test due to their great ductility. (Figure 1)

Statistical Analysis:

With SPSS (Version 24; SPSS, Chicago, IL, USA), data analysis was done. The descriptive statistics (mean and SD) were provided. The Shapiro-Wilk test was used to check for homogeneity of variance and normality of distribution. The parametric two-way ANOVA with post hoc analysis was used to analyze the differences between the groups and their interventions in order to evaluate the individual comparisons at a significant level of less than 0.05. Kaplan Meier survival analysis and plots with Breslow's tests were used to assess the survival rate of the crowns.

Results:

The study included 36 samples which were divided into 3 groups of 12 samples each. Within each group, 3 subgroups were divided with 4 samples each according to the intervention given.
The fracture load of all the samples were assessed. Also for the group which underwent thermocycling and chewing stimulator, the survival rate of the crowns were also assessed.
The fracture load of the NuSmile crowns were lesser in all the intervention groups than the other two brand groups. 3M Stainless Steel crowns had high fracture resistance and among the interventions, they had highest in chewing stimulation intervention (Table 1). In all the brands, control intervention had the lowest fracture load, followed by ageing by saliva and ageing by chewing stimulator (Figure 2).

Intervention groups	Type of crowns		
	Nu Smile Zirconia crowns	Kedo Zirconia crowns	3M Stainless steel crowns
Control	1595.63±412.03	2100.57±1004.89	2105.56±951.56
Ageing with saliva	1685.85±589.23	4226.95±389.32	4368.78±603.78
Chewing stimulation	2102.63±987.56	4389.52±358.89	4397.56±426.27

Table 1 : Descriptive distribution of fracture load among the study groups

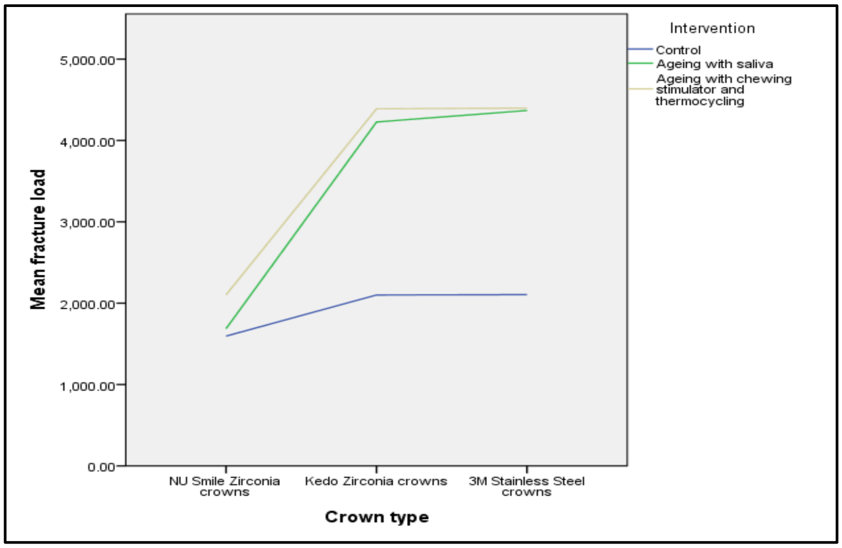

Figure 2 : Distribution of fracture load according to the brand and intervention

Figure 2 shows the Distribution of fracture load according to the brand and intervention Two way ANOVA revealed that the intervention or brand significantly had an influence on the fracture load individually (p = 0.000), but their combination did not significantly affect the fracture load (p = 0.06) (Table 2).

Tests of Between-Subjects Effects

Dependent Variable: fracture load

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	40129018.648[a]	8	5016127.331	10.662	.000
Intercept	242515142.101	1	242515142.101	515.486	.000
Crowntype	19526654.363	2	9763327.181	20.753	.000
Intervention	15441948.177	2	7720974.089	16.412	.000
Crowntype * Intervention	5160416.108	4	1290104.027	2.742	.061
Error	8468268.618	18	470459.368		
Total	291112429.367	27			
Corrected Total	48597287.266	26			

Table 2 : Two way ANOVA showing the effect of intervention and brand on fracture load

Further analysis of post hoc revealed that, with respect to the type of crown, 3M Stainless Steel crowns had the highest fracture load followed by Kedo zirconia and NUSmile zirconia. But the difference between the 3M SS crown and Kedo Zirconia was not significantly different whereas NUSmile had significantly lesser fracture load than the other two brand groups (Table 3).

(I) Crown type	(J) Crown type	Mean Difference (I-J)	Sig.
NU Smile Zirconia crowns	Kedo Zirconia crowns	-1777.6433*	.000
	3M Stainless Steel crowns	-1829.2633*	.000
Kedo Zirconia crowns	NU Smile Zirconia crowns	1777.6433*	.000
	3M Stainless Steel crowns	-51.6200	.986
3M Stainless Steel crowns	NU Smile Zirconia crowns	1829.2633*	.000
	Kedo Zirconia crowns	51.6200	.986

Table 3 : Post hoc tests showing the differences among the brand in having fracture load

Similarly, Tukey’s post hoc analysis between the intervention revealed that ageing by chewing stimulator and thermocycling had highest fracture load followed by ageing by saliva and the control group. But the difference between the chewing stimulator and saliva were not significantly different whereas control group had significantly lesser fracture load than the other two intervention groups (Table 4).

(I) Intervention	(J) Intervention	Mean Difference (I-J)	Sig.
Control	Ageing with saliva	-1493.2733*	.001
	Ageing with chewing stimulator and thermocycling	-1695.9833*	.000
Ageing with saliva	Control	1493.2733*	.001
	Ageing with chewing stimulator and thermocycling	-202.7100	.807
Ageing with chewing stimulator and thermocycling	Control	1695.9833*	.000
	Ageing with saliva	202.7100	.807

Table 4: Post hoc tests showing the differences among the intervention in having fracture load

According to a Kaplan Meier survival analysis, two of the four NU-Smile crowns did not survive (with a 50% survival rate), whereas the SSC's and Kedo zirconia crowns were able to withstand the stress of a chewing simulation with a 100% survival rate. The development of fatigue cracks or holes in the occlusal surface was the cause of the failure. This led to a significant difference ($P < 0.004$) between the NU-Smile zirconia crown and the other crowns under investigation (Table/Fig 3).

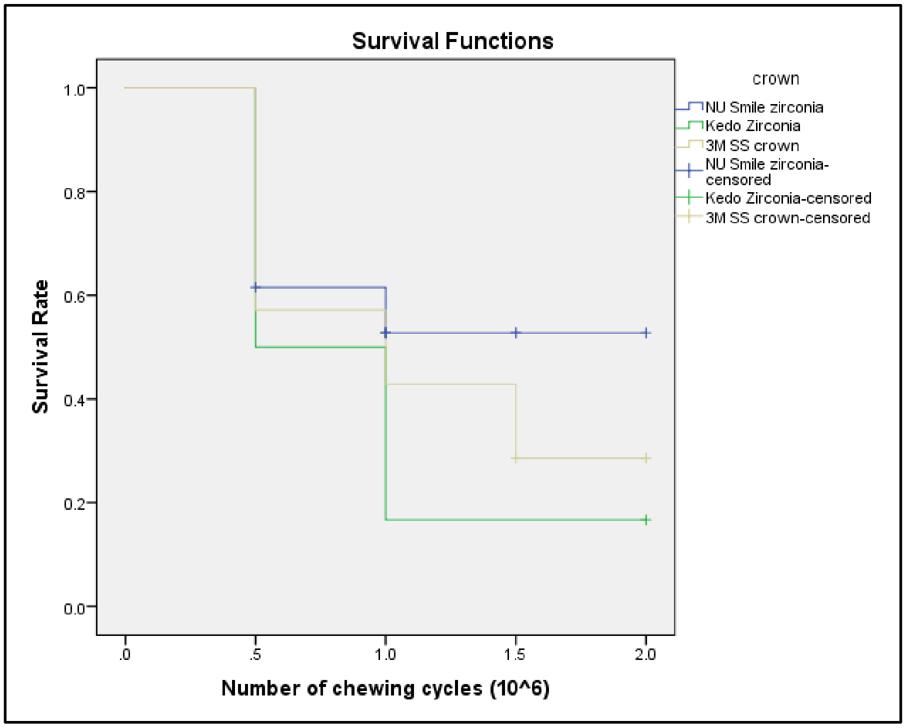

Figure 3. Results of the Kaplan-Meier survival analysis following 1.68 x 10^6 chewing simulation cycles (corresponding to approximately 7 years of clinical usage).

Discussion:

This study sought to determine the fracture load and survival rate of various crowns for primary molars, given the growing awareness of aesthetics and gingival health concerns in pediatric dentistry. In order to properly evaluate these findings, the mean maximum bite force for children aged 3 to 5.5 years old has been found to be between 186.2 and 235 N, and for children aged 6 to 11 years old, it is between 330.5 and 374.4 N (19,20).

Standardized steatite balls were employed in this investigation to measure the fracture load because they are a common antagonist used in wear simulation studies (16). This material's modulus of elasticity is comparable to that of enamel. Due to its high thermal conductivity and resistance to thermal shock, steatite was able to endure the chewing simulator's continuous force and thermocycling procedure. Since the steatite balls were employed as antagonists in both study groups and had an elasticity modulus that was comparable to enamel, they had no effect on the current study's findings (21,22). Furthermore, the outcomes of the SS and Kedo zirconia crowns were also satisfactory. Therefore, it can be inferred that the two materials' attributes in this investigation are comparable to those of the materials Daou assessed in his earlier work (23).

In the present study, the chewing simulator's thermocycling temperature was mimicked to replicate the oral environment. It fluctuated between 10 and 60 degrees Celsius (24). This was a standard procedure followed in the investigations listed earlier. This standardized protocol did not have any confounding effects in the current investigation because it was followed. For every sample, a uniform axis origin was determined, and a 2 mm radius was permitted for x, y, and z-axis movement. A constant force of 200 Ncm 1 was applied to each sample for the same number of cycles (120,000 cycles) (25).

The antagonists were found to migrate from the buccal to the lingual regions, with a loading time of 30 seconds for heat cycles. As previously noted in the experiments (26) , the occlusion was established as a cusp to the fossa in relation to the steatite balls occluding with the central fossa of the crowns. For this investigation, the chewing simulator was standardized by the manufacturer. It can therefore be ruled out as a confounding factor.

The fracture properties (load and pattern) of veneering and monolithic zirconia on posterior restorations composed of Lava Plus and Zirconia, respectively, were compared in a study by Lopez Suarez et al. The findings yielded fracture load values that the author considered clinically acceptable. The fracture load did not differ across the groups (27). The veneering ceramic cracked differently, exhibiting fracture patterns distinct from those of the framework.

In a similar study, Alshiddi et al. investigated the impact of dimension/size and the microcracks created by diamond burs during the milling process on the implant-supported cantilever zirconia frameworks that were built using CAD/CAM technology and their fracture resistance. Significant differences in the fracture load were seen between the implant-supported cantilever zirconia frameworks with varying distal abutment thicknesses and cantilever lengths (28).

In the present study, two zirconia crowns had significant differences between in each other on both fracture load nd survival rate. Similarly, in a study done by Suchada Kongkiatkamon et al who compared the fracture resistance between 4 zirconia crowns, it was revealed that Cercon XT had significantly higher fracture load than other zirconia translucent crowns (29).

In the present study, the SS crowns had higher survival rate than zirconia crowns. Contrastingly in a study done by Kist S et al, which compared the CADCAM milled and preveneered SS and zirconia crowns, for primary molars, prefabricated zirconia crowns are aesthetically pleasing and long-lasting substitutes for stain-less steel crowns (18).

The current study also has its limitations. First it only compared the prefabricated crowns and it only compared two types of zirconia crowns. Secondly, the antagonist used in this chewing stimulator is not enamel. Thirdly, the invitro study design even though tailored according to oral cavity, cannot exactly reproduce years of chewing. Within the limitations of the study, the study showed that Kedo Zirconia crowns were equally as effective as the gold standard SS crowns. But there should be more studies done to assess the fracture load of crowns in an in-vivo environment.

Conclusion:

The results of the fracture load assessments revealed noteworthy distinctions among the three crown groups. Notably, Kedo zirconia crowns demonstrated fracture loads almost equal to stainless steel crowns, indicating their effectiveness in withstanding occlusal forces. Contrastingly, NuSmile zirconia crowns exhibited a lower fracture load than both Kedo zirconia and stainless steel crowns. While this may raise considerations about their mechanical robustness, it is essential to interpret this result in the context of specific clinical scenarios and patient demographics. The robust performance of Kedo zirconia crowns, comparable to stainless steel, offers a promising avenue for clinicians seeking alternatives with aesthetic appeal and mechanical strength.

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