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A Comparison of Flexural Strength between CAD-CAM Machine-Fabricated Zirconia Posts and Cores with Conventional Casting Methods

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Abstract

Currently, zirconia-based post and core teeth have significantly advanced in the dental industry. The present study aimed to evaluate the flexural strength of posts and cores made from zirconia using CAD-CAM technology, in conjunction with various conventional casting methods, through laboratory evaluations.The present investigation is a laboratory-scale experimentation containing a total of 28 samples, including 14 zirconia-based posts and cores, as well as 14 posts and cores made of nickel-chromium alloy by casting method. The samples were tested using the Zwick20 Universal testing machine. The samples were tested in the Zwick20 Universal testing machine. The applied compressive force on the samples was exerted by a stainless-steel device with a cone-shaped design. The applied force continued until the samples were bent, and at that point, the device indicated a decrease in pressure. Subsequently, the results were examined and verified. The experiment conducted in the lab noted that with pressure exerted on the zirconia posts and cores, breakage tended to happen at the junction where the post joins the core. Anyway, due to the very high elastic sturdiness of 80% of teeth restored with a cast post and core, stress distribution around the root dentin intensified, leading to fracturing seen in the teeth themselves. While cast posts and cores showed more excellent resistance against bending compared to those made from zirconia, the fractures occurring in teeth with zirconia posts and cores more often spanned beyond simply the reparable zone, hence making the selection of zirconia posts and cores the more sensible option in appropriate cases. In conclusion, considering the study's limitations, it can be concluded that cast posts and cores exhibited greater flexibility in resisting bending than those fabricated from zirconia using CAD-CAM technology.

Keywords: Dentistry materials, Flexural strength, Casting, Post and Core, Zirconia

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1. Introduction

The resistance to root fracture is one of the most critical factors in restoring endodontic teeth that have experienced considerable loss of crown their teeth. Endodontically treated teeth frequently exhibit compromised crown structures necessitating comprehensive restoration with post and core restorations. In conventional practice, posts and cores are typically fabricated using metallic materials, including stainless steel, titanium, and various cast metals. Due to their aesthetic appeal, biocompatibility with tissues, and satisfactory strength, ceramic posts and cores (specifically zirconia) have gained popularity over time. Although limited clinical studies have been conducted in this area, the initial findings appear promising. The word zargoon is an Arabic word that means "vermilion" and a Persian word that means "gold-colored." In 1789, the German chemist Martin Klaproth fortuitously stumbled upon zirconium dioxide, marking its accidental discovery. For an extended period, the impure variant of zirconia served as a rare pigment [1]. With origins dating back to the late 1960s, the utilization of this material showcased its efficacy in orthopedics as early as 1369, specifically regarding hip joint replacements [2]. Numerous studies carried out prior to 1990 have provided evidence indicating that zirconia did not induce any unfavorable reactions within bone and muscle tissue [3-5]. Zirconia was introduced to dentistry for the first time in the form of prefabricated posts [6]. Subsequently, it was immediately utilized to prepare implant abutments and frameworks for all-ceramic prostheses [7]. Utilizing a CAD-CAM machine is an approach employed to fabricate zirconia-based posts and cores. CAD/CAM is a terminology that encompasses a technique involving the generation of digital representations or models of objects, which are subsequently employed for the design and production of prototypes or end products utilizing computer numerical control or alternative manufacturing techniques like stereolithography. The phrase CAD/CAM refers to a method wherein digital images or models of objects are generated and employed to design and produce prototypes or completed products using methods like computer numerical control or stereolithography, among other manufacturing approaches. Nowadays, the implementation of CAD-CAM technology has significantly assisted dental professionals and laboratory technicians in fabricating dental restorations, encompassing inlays, onlays, veneers, and bridges, with exceptional accuracy in terms of their shapes and dimensions. An additional benefit associated with CAD-CAM technology is the notably reduced number of appointments required to complete a restoration [8]. A study conducted by Dayal C et al. in 2014 focused on examining and contrasting the fracture resistance of endodontically treated teeth that had been restored using fiberglass posts and zirconia posts. Forty maxillary canine teeth exhibiting comparable root anatomy were carefully selected and prepared using the crown-down technique. These teeth were subsequently categorized into two distinct groups: one group receiving fiberglass posts and the other group receiving zirconia posts. Both groups were subjected to the application of compressive force until fracture occurred. The findings derived from their investigation indicated that while long-term clinical studies are necessary to determine the success rate of zirconia posts, it was observed that zirconia posts exhibited superior fracture strength when compared to glass fiber posts [9]. Research has demonstrated that zirconia possesses significantly elevated mechanical properties in comparison to other ceramics that are currently available [10-11]. Based on the outcomes of the research, it appears that the fracture load of zirconia surpasses the magnitude of human chewing force [12]. In contrast to metals that deform under high stresses, ceramics exhibit bending behavior in response to stress, which makes them susceptible to crack propagation even at relatively low-stress levels. Specifically, the tensile strength of glass and ceramics tends to be lower [13]. According to our findings, limited studies specifically examined and compared the flexural and fracture strength of zirconia posts and cores. Consequently, the present study compared the flexural strength of CAD-CAM fabricated zirconia posts with their cast counterparts.

2. Methods

From August 2020 to August 2021, an extensive laboratory experiment was conducted at the Department of Dental Materials and Biomaterials Research Centre, Shiraz Dental School, Shiraz University of Medical Sciences. An examination was conducted on 14 zirconia posts and cores, produced using a CAD-CAM system belonging to the NOVA brand. Additionally, another set of 14 posts and cores made from nickel-chromium alloy by casting was also included in the examination. Stratified sampling was employed for this study. The inclusion criteria encompassed the requirement for good compatibility between the post and cores with the root canal of the teeth, as well as the absence of any cracks or fractures within the teeth. Conversely, posts and cores that exhibited poor fitment and the presence of any cracks or fractures within the examined teeth were considered exclusion criteria.

2.1. Research method

A collection of 28 canine and central teeth, without any apparent cracks, were carefully chosen under appropriate lighting conditions. To ensure disinfection by the ISO3696 standard, the selected samples were immersed in a 0.2% thymol solution for 24 hours. Following disinfection, the QuinTron device was employed to eliminate the surrounding soft tissue, mass, and periodontal tissue from the tooth. Subsequently, the samples were immersed in normal saline and stored at room temperature. Each root's length was determined by measuring from the labial side, starting from the CEJ region. Following removing any caries, the crown of all samples was removed using a fissure bur, maintaining a 2 mm distance above the CEJ to establish a ferrule. A uniform protocol for root canal treatment was implemented in each of the samples. To open the pathway and determine the working length, an initial stainless-steel file (MANI, Kyohara, Tochigi, Japan) was placed inside the canal, accompanied by the preparation of parallel radiographs. Following recording the working length, which was set 0.5 mm shorter than the radiographic apex, the canal was cleaned and shaped by the Step back method. The Master Apicalfile was set at 35 for every tooth type. All the samples were shaped up to file number 50, regardless of tooth type. A 5.225% sodium hypochlorite solution was utilized to wash the canals. After taking a final radiograph, the canals were filled with size 35 gutta-percha (Gapadent Co, LTD, Tian jin city, China) and sub-25 gutta-perchas using the lateral condensation technique with an AH26 eugenol-free sealer (Densply). A radial shoulder finish line was placed 0.5 mm above the CEJ on all buccal, lingual, mesial, and distal tooth surfaces, creating a 1 mm broad ferrule effect around each tooth sample. This provided a 2 mm of ferrule effect on every sample. Afterward, using Peeso Reamers of sizes 2 and 3, considering the working length, the amount of gutta-percha was reduced until only 4 mm was left to establish an apical seal. Duralumin was used to create the post pattern, which was later subjected to scanning. Subsequently, zirconia posts and cores were fabricated, while the laboratory produced cast posts and cores using the molded duralumin. Before being tested, the samples underwent etching with 37% phosphoric acid. Following a thorough rinse and drying, bonding (Meta P&Bond) was administered and exposed. Ultimately, the posts and cores were affixed using Duo-Link Universal adhesive cement. Consequently, the posts were directly positioned onto the canal and secured in place, followed by applying finger pressure to hold the posts and cores for 1 minute. Simultaneously, the excess cement was carefully eliminated using a micro brush, ensuring thorough removal from both the buccal and lingual directions, with an exposure time of 40 seconds. Subsequently, the cemented posts and cores were placed in a controlled environment with optimal humidity levels, maintained at 100% for one week.

To facilitate the required force test for failure, the samples were prepared and mounted in a manner suitable for compressive loading. The Universal testing machine Zwick 20 was utilized to conduct the test, ensuring accurate measurements and analysis. Using this method, the teeth were mounted parallel to their longitudinal axis, elevated by 1 mm above the CEJ within self-curing acrylic material (Acropars self-cure acrylic, sourced from Iran). To apply a force at a 45-

degree angle, the samples were positioned within a specialized holder. The Zwick 20, a universal testing machine, exerted force during the experiment. Utilizing hardened steel balls measuring 5 mm in diameter, the labial region of each tooth underwent force application at a velocity of 0.5 mm per minute. In every sample, the initial decline observed on the stress graph is identified as the point of fracture, prompting the termination of force application.

2.2. Data analysis

Data analysis was done using SPSS-22. Independent t-tests and Tukey Honest Significant Differences (Tukey HSD) were used to compare the groups in terms of their percentage of failure, modes, and the average and variability of sample fracture strengths. Statistical significance was set at a p-value below 0.05.

3. Results

The sample size was determined based on the available resources and seeking 95% confidence with up to 110 maximum error. This was calculated using Kekran's formula for 28 teeth, with a standard deviation of 299.303 taken into account. The data in Table 1 show the mean flexural strength and fracture values for the cast and zirconia post cores were 1444.43 and 1123.29, respectively. The associated standard deviations were 319.398 and 168.841, respectively. The Kolmogorov–Smirnov test was used to separately assess the normality of flexural strength and fracture data for the cast and zirconia post and cores. Normality was confirmed for each (P1=0.2, P2=0.2, with P>0.05 in all cases).

Based on the findings of this research, the mean flexural strength for post and cores in the casting and zirconia groups were 1444.43 and 1123.29, respectively. The standard deviation for flexural strength of post and cores in the casting and zirconia groups were 319,398 and 168,841, respectively. There was a statistically significant difference between the average strengths of the two groups, as presented in Table 2. Therefore, it can be concluded that the flexural strength of posts and cores in the casting group was more significant than the zirconia group, as shown in Table 3. An independent t-test showed a significant difference between the two groups (t (26)=3.326, P=0.003). Using posts and cores for restoring root canal-treated teeth has always been of interest. Teeth undergoing root canal treatment are at a higher fracture risk due to the extensive damage to the dental structure. To achieve optimal reconstruction of these teeth, using posts as appropriate retainers is imperative. Due to their exceptional physical properties, cast metal posts and cores have been used successfully for a long time. However, due to their elevated elasticity modulus, there is an increase in the accumulation of stress around the root dentin, rendering the tooth susceptible to fractures.

The rising need for restorations that prioritize aesthetics and biocompatibility has stimulated the advancement of post and core systems that are tooth-colored, translucent, and devoid of metal components. To address this issue, introducing pre-made zirconia ceramic posts and cores has provided a solution that enables the preservation of the translucency of all ceramic crowns. The considerable and broad interest in utilizing zirconia ceramic posts has resulted in a substantial body of laboratory studies focusing on zirconia posts over the past 15 years. Typically, posts and cores are manufactured through either casting systems or computer-aided design and computer-aided manufacturing (CAD-CAM) processes. The amount of healthy remaining tooth structure directly influences the bending resistance of the tooth. Generally, teeth with a diminished crown structure or smaller crown size are commonly treated with cast posts and cores. Zirconia has emerged as a viable material for fabricating non-metal posts and cores. This particular material can address aesthetic concerns when performing repairs in critical areas, and its exceptional durability allows for its application even in posterior regions of the oral cavity. Utilizing a CAD/CAM system is among the innovative approaches for fabricating these restorations. Based on the research conducted by Dr. Sadeghi et al. (14), it was found that cast posts and cores exhibited superior fracture resistance compared to zirconia fiber posts and quartz fiber posts.

A study performed by Amin et al. indicated that the mean fracture resistance and corresponding standard deviations for the glass fiber, ceramic, and metal categories were as follows: 113.26±765, 95.34±790, and 105.32±614, respectively. No considerable difference was observed in resistance between the glass fiber and ceramic groups; however, both glass fiber and ceramic posts exhibited significantly more excellent fracture resistance than titanium posts. Based on the findings of this study, the utilization of premanufactured glass fiber and ceramic posts is deemed more favorable compared to premanufactured metal titanium posts. However, considering the higher incidence of unfavorable fractures within ceramic groups compared to glass fiber, it is recommended to use glass fiber posts [5]. This study investigated the flexural strength of CAD-CAM-fabricated zirconia posts and cores compared to conventional casting methods. The results revealed a significant difference between these two categories of posts and cores regarding their flexural strength. Several factors, including the integrity and quantity of the remaining tooth structure, air entrapment within the core material, and the thickness of the cement, have the potential to elevate the standard deviation (SD) and coefficient of variance (CV) in this study. Besides, the outcomes derived from this laboratory-based study may not precisely reflect the conditions present in the body's internal conditions. For example, the assessment of failure resistance is done by the application of substantial force at a specific point. Conversely, intraoral fractures typically arise from the cumulative effect of light or moderate loads exerted over an extended duration. Consequently, further investigations are warranted to develop improved methodologies that closely resemble the clinical mechanisms of dental failure and restorations [14]. According to a study, the mean force exerted during chewing and swallowing by individuals is recorded at 40 newtons, while the maximum chewing force exerted on posterior teeth ranges from 200 to 540 newtons [16]. Furthermore, another study revealed that average chewing forces range from 11 to 150 Newtons.

Table 1. The mean and standard deviation of the flexural strength between cast and zirconia post and core groups

		Casting	Zirconia
Average strength		1444.43	1123.29
Adjusted mean without 5% up and down	Lower limit	1260.01	1025.80
	Upper limit	1628.84	1220.77
Adjusted mean without 5% up and down		1441.59	1117.04
Median		1410.00	1101.50
Variance		102015.341	28507.297
Standard deviation		319.398	168.841
Minimum		990	879
Maximum		1950	1480
Domain		960	601
Mid-quartile range		530	261
Crookedness		0.263	0.638
Kurtosis		-1.093	0.063

Table 2. Comparing the average flexural strength and fracture of post and cores in two groups of casting and Zirconia

Stability	N	Mean	Standard deviation	Standard error	Adjusted mean without 5% up and down		Minimum	Maximum
					Lower limit	Upper limit		
Casting	14	1444.43	319.398	85.363	1260.01	1628.84	990	1950
Zirconia	14	1123.29	168.841	45.125	1025.80	1220.77	879	1480
Total	28	1283.86	299.303	56.563	1167.80	1399.91	879	1950

Table 3. Comparing the Mean Flexural Strength and Fracture Rates of Post and Cores Between Cast and Zirconia Groups Using a T-test

	Levene Test for Equality of Variances		T-test to check the equality of means						
	F	Sig.	T	DF	Sig. (2-tailed)	Average difference	Standard error	95% Confidence Interval of the Difference	
								Lower	Upper
equal-variance assumed	6.495	0.017	3.326	26	0.003	321.143	96.556	122.669	519.616
Equal variances not assumed.			3.326	19.739	0.003	321.143	96.556	119.560	522.726

The uppermost estimation reaches 200 newtons for anterior teeth, 350 newtons for posterior teeth, and 1200 newtons in individuals with parafunctional habits [17]. In the present study, the zirconia group demonstrated the capacity to withstand loads ranging from a minimum of 852 newtons to a maximum of 1560 newtons, while the casting group displayed load-bearing capabilities ranging from a minimum of 871 newtons to a maximum of 1990 newtons. Consequently, the choice of post and core type that is most appropriate for a patient can be determined based on their circumstances and the presence or absence of parafunctional forces. The present study revealed an association between the type of cement employed for the cementation of posts and cores and their resistance to failure. Furthermore, it is worth noting that all the tests were conducted under dry conditions, even though previous research has indicated that wet environments can influence the strength of prosthetic materials. During the experimentation, it was discovered that zirconia posts and cores tended to gradual crack propagation when subjected to power loading cycles in a moist environment. The concurrent presence of moisture and operational stress elevates the potential for cracking and diminishes the force threshold necessary for failure [18]. Given the perpetually moist nature of the oral environment, it is crucial to take into account the continuous exposure of prosthetic restorations to moisture and its potential impact on alterations in the strength properties of materials. Another limitation of this study was its extramural implementation, whereby the posts and cores were positioned uniformly under force, neglecting the complex nature of forces within the oral cavity. It is essential to consider that the procedure for a dental filling followed by restoring them using posts and cores can potentially induce surface cracks, thereby compromising the strength of the dental post and core.

4. Conclusions

Zirconia posts and cores manufactured using the CAD-CAM method exhibit lower average flexural strength than cast posts and blinds. During this laboratory investigation, when force was applied to the zirconia posts and cores, it was noted that bending was primarily observed in the connection region between the post and the core. However, in 80% of the teeth restored using posts and cores, the elevated modulus of elasticity led to stress accumulation around the root dentin, resulting in tooth fractures. Although the fracture resistance of posts and cores surpassed that of zirconia posts and cores, the occurrence of fractures within the zirconia posts and cores themselves, rather than in the reparable area, suggests that selecting zirconia posts and cores may be more reasonable in appropriate cases.

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