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ORIGINAL ARTICLE

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Fracture Resistance of Anterior CAD/CAM Nanoceramic Resin Endocrowns with Different Preparation Designs

Resistência à Fratura de Endocrowns de Resina Nanocerâmica CAD / CAM Anterior Com Diferentes Projetos de Preparação

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ABSTRACT

Objective: The aim of the study was to evaluate the effect of extension of endocrown in pulp space and the effect of ferrule on the fracture resistance of anterior endocrowns made of nanoceramic resin blocks. **Material and Methods:** Twenty-eight freshly extracted human upper central incisor teeth were prepared to receive CAD/CAM nanoceramic resin endocrowns with four different designs. The specimens were divided into two groups ($n = 14$) according to the extension of the endocrown inside root canal (A:short and B:long), then each group was further subdivided into another two subgroups ($n = 7$) according to the presence or absence of ferrule effect (1:ferrule and 2: no ferrule). Endocrowns were then fabricated using CEREC in lab and nanoceramic resin blocks (DENTSPLY Sirona, Germany) and LAVA ultimate (3M ESPE, Germany) blocks size 14L. **Results:** Two-way ANOVA showed that the ferrule ($p > 0.0001$) had statistically significant effect on the fracture resistance. However, the extension of the endocrown into the canal had no statistical significant effect on the fracture resistance ($p = 0.837$). The interactions between the independent variables (extension into the canal and ferrule) had statistically significant effect on the fracture resistance ($p = 0.029$). Load to fracture for group 1A was 439.53 N, 1B was 306.46 N, 2A was 516.29 N and 2B was 242.04 N. **Conclusions:** Fracture resistance was not improved by the long or short extensions of the

RESUMO

Objetivo: O objetivo deste estudo foi avaliar o efeito da extensão da coroa endocrown na câmara pulpar e o efeito férula na resistência à fratura de coroas endocrowns anteriores confeccionadas através de blocos de resina nanocerâmica. **Material e Métodos:** Vinte e oito dentes incisivos centrais superiores humanos recém-extraídos foram preparados para receber endocrowns de resina nanocerâmica CAD / CAM com quatro diferentes tipos de preparos. Os espécimes foram divididos em dois grupos ($n = 14$) de acordo com a extensão da endocrown dentro do canal radicular (A: curto e B: longo), então cada grupo foi subdividido em outros dois subgrupos ($n = 7$) de acordo com presença ou ausência do efeito férula (1: com férula e 2: sem férula). As endocrowns foram usinadas através do CEREC In Lab e blocos de resina nanocerâmica (DENTSPLY Sirona, Alemanha) e blocos de LAVA ultimate (3M ESPE, Alemanha) tamanho 14L. **Resultados:** ANOVA dois fatores demostrou que a férula ($P > 0,0001$) teve efeito estatisticamente significativo na resistência à fratura. No entanto, a extensão do endocrown no canal não teve efeito estatisticamente significativo na resistência à fratura ($P = 0,837$). As interações entre as variáveis independentes (extensão no canal e férula) tiveram efeito estatisticamente significativo na resistência à fratura ($P = 0,029$). A carga para fratura do grupo 1A foi de 439,53 N, 1B foi de 306,46 N, 2A foi de 516,29 N e 2B foi de 242,04 N. **Conclusões:** A resistência à fratura não foi melhorada pelas extensões longas ou curtas endocrowns in the pulp space, however, the ferrule effect shows significant improvement of the fracture resistance of the nanoceramic resin endocrowns.

KEYWORDS

Anterior endocrowns; Endocrown extensions; Fracture resistance; Nanoceramic resin blocks.

das endocrowns na câmara pulpar, no entanto, o efeito férula mostrou uma melhora significativa na resistência à fratura das coroas endocrowns de resina nanocerâmica.

PALAVRAS-CHAVE

Endocrowns anterior; Extensão da endocrown; Resistência à Fratura; Bloco de resina nanoracerâmica.

INTRODUCTION

The rehabilitation of severely damaged coronal hard tissue in endodontically treated teeth is always a challenge in reconstructive dentistry [1]. The loss of structural integrity increases the occurrence of crown fractures and microleakage at the margins of restorations compared with 'vital' teeth [2].

The upper anterior teeth show high rates of fracture, especially central incisors in young age, mainly due to trauma. There are limited restorative options that ensure proper mechanical, biological and esthetical results. This proposed new designing and manufacturing technology, also the materials and the bonding characteristics offered new modalities of treatments to obtain better solutions for the badly mutilated endodontically treated upper anterior teeth [3].

Rigid restorations that are adhesively retained to the remaining tooth structure may offer good support and distribute the stress uniformly; however, if the tooth is overloaded, a catastrophic failure may result [2]. A more elastic restoration may bend under high loads concentrating the stresses along the adhesive interface resulting in loss or failure of the restoration but would leave the root intact for retreatment [4].

Resin-based materials are believed to be more resilient than ceramic materials which enhance the dampening effect of the material. Moreover, the material is much easier to grind by different milling tools and more repair-friendly in case of chipping or fracture of the restoration [4,5].

The recent developments of adhesive techniques and ceramic materials facilitated the avoidance of possible operational errors during post space preparation [2], by introducing the so called endocrowns. The use of endocrowns restorations presents the advantage of reducing the interfaces of the restorative system [6], decreasing the amount of preparation needed inside the root canal, enhancing the structure durability of the tooth structure [7].

Endocrowns were traditionally fabricated to restore molar teeth providing high fracture resistance and attractive esthetic results. More failure rates were noted in premolars than molars [8]. However, in current literature it is difficult to find studies that analyze the fracture resistance and mode of failure of endocrowns in anterior endodontically treated teeth, and the use of endocrowns in anterior teeth is still debatable [9].

Indirect resin endocrowns can be constructed by CAD/CAM techniques using the prefabricated resin nanoceramic resin blocks under controlled conditions, which according to the manufacturer combine some of the best attribute of the porcelain and the polymers [6]. Restorations milled from CAD/CAM resin nanoceramic composite blocks have many advantages including easier intraoral finishing and polishing, less abrasiveness to the opposing dentition, and ease of additions/adjustment [6].

The null hypothesis tested were that:

[1] The extension of the endocrown inside the root canal will have no effect on the fracture strength of the endodontically treated anterior

tooth.

[2] The absence of ferrule effect will not affect the fracture strength of the endodontically treated anterior tooth.

The aim of this in vitro study was to evaluate the effect of the extensions of endocrowns in the root canal and the ferrule effect on the fracture resistance of anterior endocrowns by using CEREC CAD/CAM nanoceramic resin blocks.

MATERIAL AND METHODS

A power analysis was designed to have adequate power to apply a 2-sided statistical test of the research hypothesis that there is no difference in fracture resistance of different tested groups. Effect size (d) was calculated and found to be (1.22). By adopting an alpha (α) level of 0.05 (5%), and a beta (β) level of 0.20 (20%) i.e. power = 80%; the predicted sample size (n) was found to be a total of (24) samples i.e. (12) samples per group, (6) for each subgroup.

Samples preparation

Twenty-eight freshly extracted human upper anterior teeth with approximate similarity in size, shape, and crown morphology were collected. The teeth were stored in distilled water once collected and throughout all the steps of the study. The teeth length was approximately (15 mm ± 0.5) from the cervical line to the apex. Labiolingually, they were 6 mm ± 0.5 mm from the most apical point of the cervical line labially to the most apical point of the cervical line palatally. While mesiodistally, they were 5 mm ± 0.5 mm from the most coronal point of the cervical line mesially to the most coronal point of the cervical line distally.

Teeth were divided into two groups (n = 14). Samples of group A received endocrowns with short extension (2 mm) while group B received endocrowns with long extension (5 mm). Each of the two groups was further divided into two subgroups (n = 7). Subgroup 1 is prepared with ferrule while subgroup 2 without ferrule.

Groups A1 and B1 were decoronated 2 mm above cemento-enamel junction (CEJ) to provide a ferrule. While groups A2 and B2 were decoronated at the same level of CEJ (Figure 1). All samples were endodontically treated and individually mounted vertically in polymethyl methacrylate (PMMA) resin blocks to a depth of 2 mm apical to the CEJ, to facilitate handling.

Decoronation was made using a water-cooled diamond rotary cutting instrument, and the coronal portions of all teeth were sectioned perpendicular to the long axis.

CNC (computer numerical control) milling machine (DAHUI MACHINE TOOL CO., LTD. CHINA) was used to prepare the extension inside the root canal, 2 mm depth in groups A1 & A2 (Figure 2), and 5 mm depth in groups B1 and B2. The ferrule design in groups A1 and B1 was also prepared by CNC machine by making a deep chamfer finish line of 1mm thickness and with 6-degrees taper. (Figure 3a,3b).

Teeth were then scanned, endocrowns were designed (Figure 4) and milled using CEREC CAD/CAM system (DENTSPLY Sirona, Germany) and LAVA ultimate (3M ESPE, Germany) blocks size 14L (Figure 5a,5b). Endocrowns were then cemented using Bifix QM resin cement (VOCO America), which is a dual-curing universal composite-based luting system with ceramic bond.

Fracture resistance testing

All specimens were stored in distilled water in sealed containers at room temperature for a period of 48 hours before testing. A specially designed attachment fabricated for mounting teeth with an inclination of 130 degrees was used during carrying out the fracture resistance test (Figure 6). The teeth were secured to the lower fixed compartment of a computer controlled universal testing machine (Lloyd LR5K, England). Load was applied at a crosshead speed of 1 mm/min using a custom-made load applicator attached to the upper movable compartment of the machine. Maximum load was obtained in Newton (N). Failure was manifested by audible crack sound and confirmed by sudden drop along load deflection curve recorded by Nexygen computer software (Lloyd LR5K, England). Failure loads were measured using the machine with a load cell of 5 KN and data were recorded.

SEM analysis to analyze failure modes

Fractured samples were examined under a scanning electron microscope (Quanta 250 FEG; FEI, Netherlands) with an accelerating voltage of 30 kV at a magnification of 40x to define the failure modes (Figure 7) which were classified as:

Mode A represents fracture in the coronal portion of the restoration (repairable) (Figure 8a,8b)

Mode B represents fracture in the radicular portion of the restoration (repairable) (Figure 9a,9b)

Mode C represents fracture in the cervical portion of the tooth (above the bone level-repairable) (Figure 10a,10b)

Mode D represents fracture in the mid-root or apical portion of the root (below the bone level-catastrophic). (Figure 11a,11b)

Mode E represents debonding of the restoration without fracture in the tooth or the restoration (catastrophic). (Figure 12a,12b)

Table I - Number of specimens and the percentage (%) of each failure mode in each experimental group

Group	Subgroup	Mode A	Mode B	Mode C	Mode D	Mode E
1. Short extension	A. Ferrule	4 (57%)	2 (29%)	1 (14%)	0 (0%)	0 (0%)
	B. No ferrule	3 (43%)	2 (29%)	1 (14%)	0 (0%)	1 (14%)
2. Long extension	A. Ferrule	1 (14%)	3 (43%)	2 (29%)	1 (14%)	0 (0%)
	B. No ferrule	1 (14%)	4 (57%)	0 (0%)	1 (14%)	1 (14%)

Statistical analysis

Statistical analysis was performed in several steps. Two-way ANOVA was performed to evaluate the effect of ferrule and extension of the endocrowns on the fracture resistance, and the interaction between ferrule and the extension of the endocrown. One-way ANOVA followed by Tukey HSD post hoc test were performed to evaluate the effect of different endocrown designs on the fracture resistance. The results were then represented on a column chart showing the mean fracture resistance values for all groups.

RESULTS

There was statistical significant difference between fracture resistance of endocrowns with and without ferrule. There was no statistical significant difference between fracture resistance of endocrowns with long and short extension (Table I).

The lowest mean fracture resistance was recorded in long extension endocrowns without ferrule group (242.04 ± 92.91N) while the highest fracture resistance was recorded in long extension endocrowns with ferrule group (516.29 ± 40.99 N).

Table II - Mean fracture resistance ±SD recorded in Newton for all groups

Subgroup	1A Short with ferrule	1B Short without ferrule	2A Long with ferrule	2B Long without ferrule	
Fracture resistance Mean (N) ± SD	439.53 ± 35.45	306.46 ± 76.15	516.29 ± 40.99	242.04 ± 92.91	
Rank	B	A	B	A	p= 0.001

A. Effect of ferrule on fracture resistance

The mean and standard deviation values of fracture resistance of endocrowns with ferrule were 477.91 ± 54.24N and 274.25 ± 86.99N without ferrule.

There was statistically significant difference between fracture resistance of endocrowns with and without ferrule.

B. Effect of extension on the fracture resistance

The mean and standard deviation values of fracture resistance of endocrowns with long extension were 379.16 ± 159.61N and 372.99 ± 89.75N with short.

There was no statistically significant difference between fracture resistance of endocrowns with long and short extension.

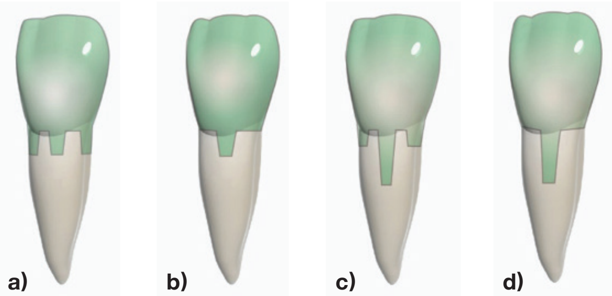

Figure 1 - Diagram showing different preparation designs for all groups: a) Short extension with ferrule, 1 mm deep chamfer finish line, 2 mm extension from cavosurface margin inside pulp space; b) Short extension without ferrule, 2 mm extension from CEJ inside pulp space; c) Long extension with ferrule, 1 mm deep chamfer finish line with 5 mm extension from cavosurface margin inside pulp space; d) Long extension without ferrule, 5 mm extension from CEJ inside pulp space.

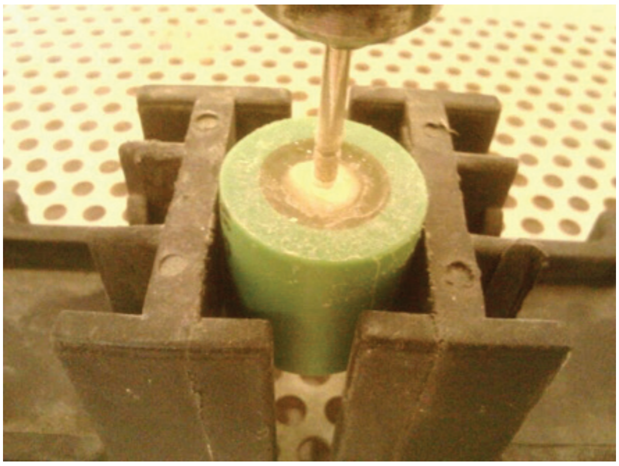

Figure 2 - Abrasive stone attached to the stylus of the CNC machine preparing the post space to produce the central cavity extension.

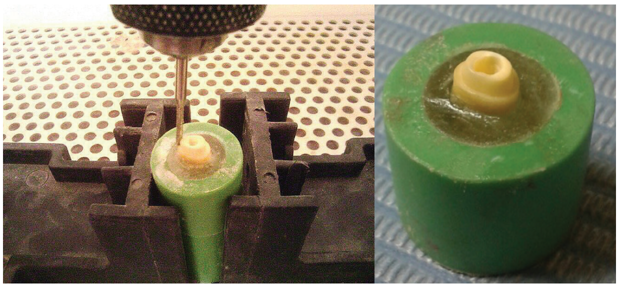

Figure 3 - a) Finish line preparation using CNC (groups A1 and A2 with ferrule); b) Group A1 (short extension with ferrule effect).

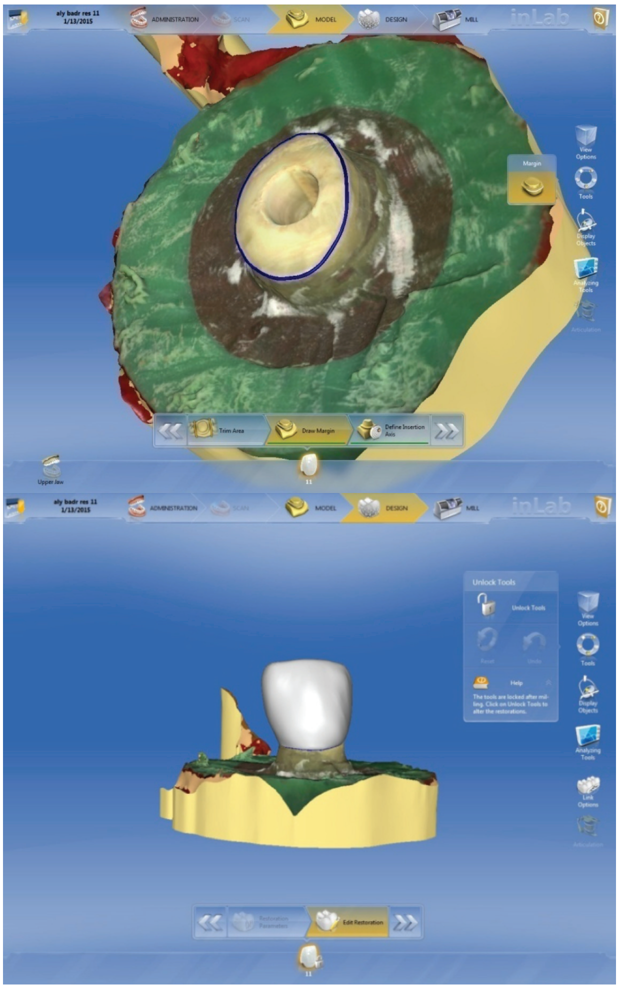

Figure 4 - Computer designing.

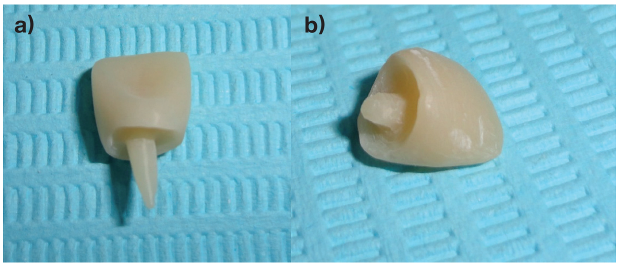

Figure 5 - a) Long extended endocrown; b) Short extended endocrown.

Figure 6 - Specially designed attachment, custom-made load applicator, and 130 degrees inclination of the sample.

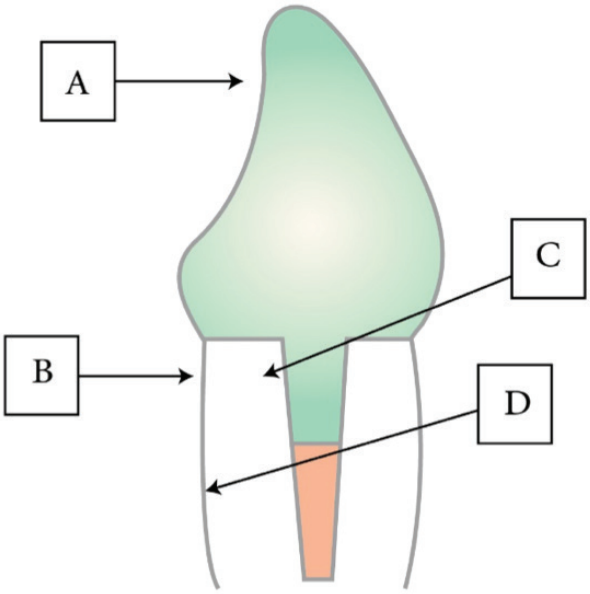

Figure 7 - Mode of failures.

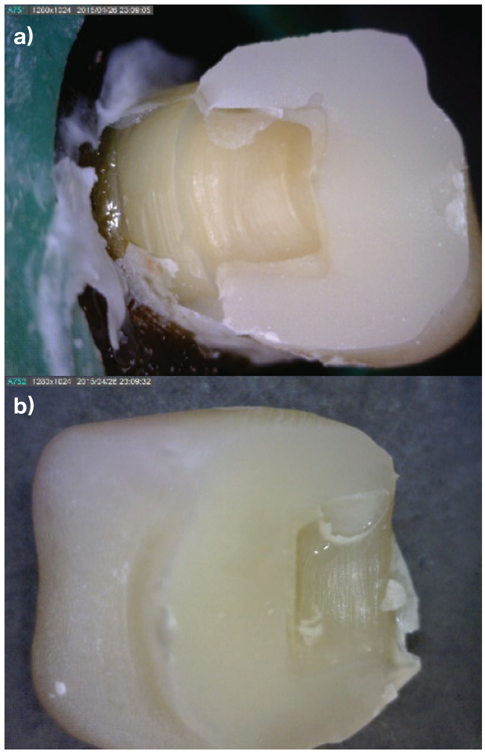

Figure 8 - a,b: Mode of failure A.

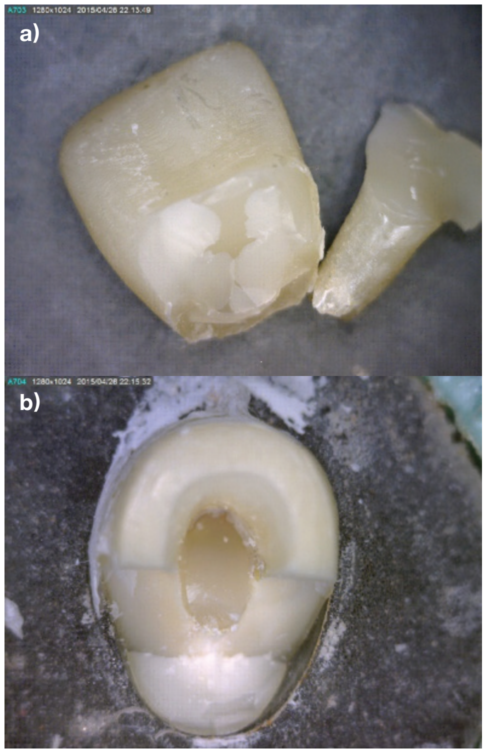

Figure 9 - a,b) Mode of failure B.

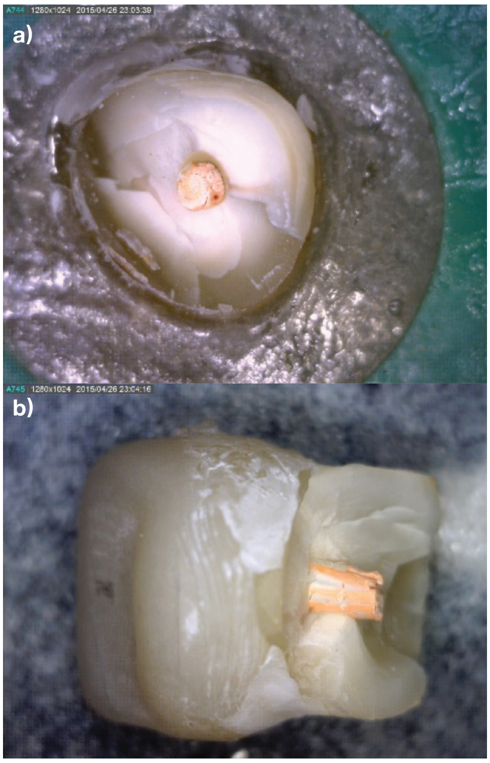

Figure 10 - a,b) Mode of failure C.

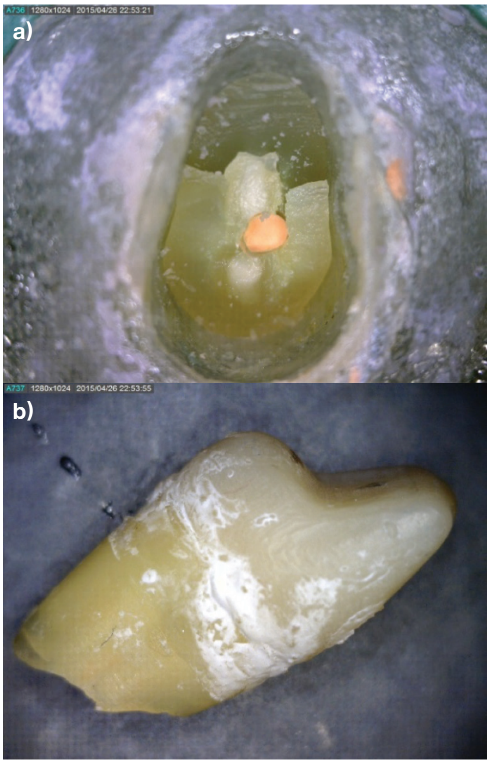

Figure 11 - a,b) Mode of failure D.

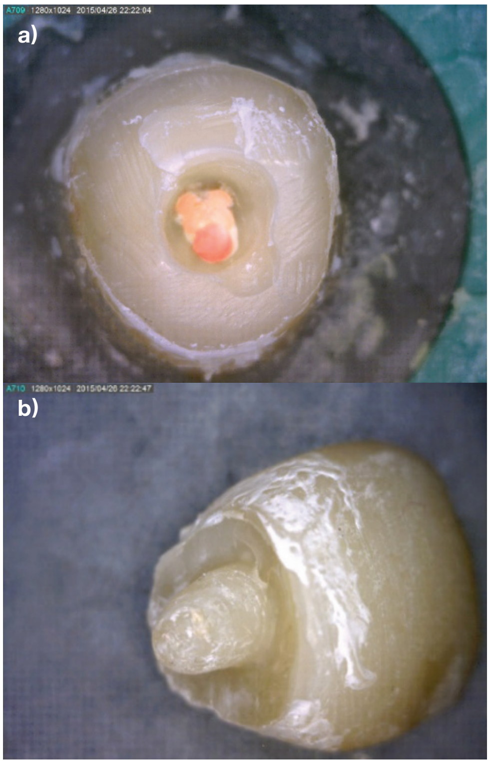

Figure 12 - a,b) Mode of failure E.

DISCUSSION

The *null hypothesis* that the extension of the endocrown inside the root canal will have no effect on the fracture strength of the endodontically treated anterior tooth was accepted. However, the hypothesis that the absence of ferrule effect will not affect the fracture strength of the endodontically treated anterior tooth was rejected, because the study proved that there is statistical significant difference between fracture resistance of endocrowns with and without ferrule.

After root canal treatment, the dental practitioner is faced with the task of restoring the tooth to rehabilitate oral functions. There is often insufficient dental hard tissue left to ensure adequate retention of a functional restoration after endodontic treatment [5].

Central incisors were chosen for this study due to their frontal position in the oral cavity that made them more prone to traumatic fractures than any other tooth in the oral cavity, especially in young age [6].

The ferrule effect was chosen as a variable in this study because many studies indicated that the presence of remaining tooth structure for ferrule preparation did influence the fracture resistance of the teeth [7], and that fracture resistance was best for test specimens with longest ferrule [8]. Also, the extension of the endocrown in the root canal appears to be an important variable in assessing fracture resistance [9].

CNC machine was used in preparation of the long and short extensions endocrowns to standardize the dimensions of the central cavities without undercuts in every tooth. It was also used for the preparation of the ferrule with standardized measures of 1 mm-wide, 2 mm axial wall heights, and 6 degrees taper were made and reduction was following the CEJ. Deep chamfer finish line was made to avoid the sharp lines of the shoulder finish line that increase the stress concentration [10].

Lava ultimate blocks were used to produce the endocrowns. These blocks are composed of nanoceramic particles embedded in highly cross-linked resin matrix, 80% wt nanoceramic and 20% wt resin. This composition allowed milling by CEREC machine without destruction of the resin matrix due to its high cross-linking. The inclusion of nanoceramic component optimizes the surface properties of the restoration and creates a more wear-resistant, high-gloss surface finish, also it facilitated contouring and adjustments in the restoration [11]. The presence of the high resinous component of these nanoceramic composite blocks allow for relatively low modulus of elasticity (compared to ceramics), close as possible to that of the dentin which allows for more homogeneous load distribution and optimizing the stresses transferred to be equally distributed between the tooth structure and the restoration, in order to prevent catastrophic fractures of the weakened root. An important factor was the high strength of the Lava Ultimate offered by the manufacturer that allowed for decreased number of interfaces in the restoration by forming a one unit post-core-crown system with only one interface. In general the use of the endocrowns reduces the interfaces of the restorative system [11].

Milling by CEREC allows for formation of one-piece endocrown that adapts better to the root canal than a prefabricated glass fiber posts having shapes that cannot be changed and may be unsuitable for severely damaged teeth with wide root canals. In addition, CAD/CAM milling reduced the cement layer thickness. Furthermore, it does not require the use of a composite resin foundation such as customized fiber posts and cores that have three and sometimes four interfaces accounting for high failure rates and low survival rates. The adaptation of the restoration and the incisal morphology are better obtained using CAD/CAM. Moreover, the restorations can be produced and delivered in one appointment and this saves the time associated with the build-up procedure of the post and core [12].

Generally, it appeared that preserving a ferrule is beneficial to increase the fracture resistance of endodontically treated teeth [13]. This result corroborates results of previous studies, in which a ferrule of at least 1.5 mm has been reported to be efficacious for the long-term survival of restorations of endodontically treated teeth [14-17]. Some other studies indicated that the amount of axial dentin surrounded by the crown is more important than the length of the post [18-23], taking in consideration that the posts mentioned in these studies have the same bonding qualities, and can apply the monoblock as resin nanoceramic endocrowns used in this study. Zicari et al. (2013) [24] found that avoiding extra-removal of sound tooth structure, rather than placing a fiber post, can protect endodontically treated teeth against catastrophic failure. However, when any ferrule can be preserved, a fiber-post may improve the retention and fatigue resistance of the restoration. Naumann et al. (2006) [25] concluded in an in vitro study that the absence of portions of a crown ferrule (missing facial or palatal aspects, proximal interrupted) of an endodontically treated and post/core restored maxillary central incisors is associated with greater variation of failure load. Strength values might be reduced to below a clinically acceptable load bearing. This could be correlated to the results of this study as the groups containing ferrule effect showed highest fracture resistance results, and both groups not containing ferrule showed lowest fracture resistance. The most likely explanation for this result is that the cervical collar strengthened the body of the teeth due to the greater amount of tooth structure that allowed for dissipation of forces and better load distribution. In addition, the cervical collar might have more stable foundation for the endocrowns which lead to greater resistance to rotation and decreased necking of the restoration.

On the other hand, this study accounted for insignificant effect of the endocrown extension on the fracture resistance. This result of this study came congruent with other studies in literature showing the insignificance of post extension on the fracture resistance of the tooth or the restoration. The results of this study were compared to the results of studies examining post extension in the root canal because the same variable was used which was the intracanal extension, and also the material of the posts used in these studies showed close qualities to the Lava Ultimate accounting for similar bonding qualities and monoblock effect. Schiavetti and Sannino (2012) [26], concluded that post depth insertion did not affect the resistance to fracture. It could be advisable in the rehabilitation of endodontically treated teeth to preserve radicular tissue, reducing the post space preparation, in order to improve the fracture strength of the post with a ferrule length of at least 2 mm. Zicari et al. (2013) [24] also concluded that Inserting a fiber post seems not to be necessary to improve the fracture resistance of endodontically treated teeth in which a ferrule is preserved, whereas it was found to be effective in teeth without any ferrule. They also recommended avoiding extra-removal of sound tooth structure rather than using a fiber post to protect against catastrophic failures. Basically, comparing results of different studies is obviously difficult, since different set-ups and materials were used. This was manifested in this study in a way that the lowest mean fracture resistance group was that in the group containing long extension and no ferrule (242.04 ± 92.91N), so the long extension did not make a great difference, while the highest were recorded in the long extension endocrowns with ferrule group (516.29 ± 40.99 N) and short extension endocrowns with ferrule (439.53 ± 35.45 N). So it seems that the ferrule effect is the variable that has the highest effect on the fracture resistance than the endocrown extension.

Other studies showed significant effect for the endocrowns extension on the fracture resistance, which is not matching with the results of this study. Laden Gulec and Nuran Ulusoy (2017) [27], concluded that the modified endocrowns design with 3 mm intraradicular extension protected the remaining tooth structure better than the normal endocrowns design in upper maxillary first premolars. GT Rocca et al. (2017) [28] discouraged the use of flat endocrowns in premolars and concluded that the use of 2 mm and 4 mm endocrowns extensions have similar fatigue strength to classical crowns.

Analysis of the failure mode was done to evaluate the fracture pattern in each group. It was assessed either catastrophic (root fracture beyond repair) or repairable (fracture in the restoration or cervical part of the root above bone level). This was important because failure pattern indicated whether the different designs and the material used allow for repairable fractures or not. The load bearing capacity was not only related to the strength of the adhesive interfaces, but also to the design of the endocrown in simulating the structure of tooth and the material used.

Most of the failures that occurred in all groups were repairable, and were represented as fractures in the cervical portions of the root, or fractures in the restoration whether in the cervical portion of the restoration or in the junction between the coronal and radicular portion of the restoration. These modes of failures could be explained by the closeness of modulus of elasticity of the material and the dentin [11]. Also, the thick resin cement layer acted as a stress absorber which decreased the stresses falling on the root.

Recommendations

1. For more meaningful results, future studies should incorporate thermal cycling of the specimens and fatigue loading.

2. Further studies should be done with different variables to set up guidelines for the anterior endocrowns.

CONCLUSION

Under the limitation of this study, several conclusions could be obtained:

1. The endocrown extension in the root canal alone could not improve the fracture resistance of endodontically treated anterior teeth.

2. The ferrule effect improved the fracture resistance of endodontically treated anterior teeth.

Conflict of interest

The authors have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

Regulatory Statement

This study was conducted in accordance with all the provisions of the local human subject's oversight committee guidelines and policies of: Ain Shams University, Cairo, Egypt. The approval code for this study is: FDASURecEM111201.

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