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The Influence of Dentin Wall Thickness and Adhesive Surface in Post and Core Crown and Endocrown Restorations on Central and Lateral Incisors

JW Hofsteenge • MMM Gresnigt

Clinical Relevance

Post and core crowns and endocrowns perform similarly on fracture strength, but endocrowns have more repairable fractures.

SUMMARY

Purpose: The main purpose of this study was to determine the influence of dentin wall thickness (DWT) and adhesive surface on the fracture strength and failure mode in maxillary incisors restored with post and core crowns or endocrowns.

Methods and Materials: Forty-eight sound maxillary incisors were selected and randomly divided into four groups (n=12): lateral incisor endocrown, lateral incisor post and core, central incisor endocrown, and central incisor post and core. All specimens obtained an endodontic treatment and were decoronated (2 mm ferrule remained). Chamfer outlines ended at the cementoenamel junction (outline in dentin). Dentin wall thickness (mm) was measured on 12 points per sample using a modified digital calliper. Fiber posts and cores were placed in two groups, and an immediate dentin sealing was applied on exposed dentin in all groups before taking digital impressions. Digital impressions were analyzed and the adhesive surface (mm²) was measured. Indirect restorations were made of lithium disilicate (IPS e.max, computer-aided design/computer-aided manufacturing). The restorations were luted after surface conditioning the crowns and teeth. Thermocyclic aging was performed (10,000 times in baths of 5°C and 55°C) and the specimens were loaded until fracture. Fractures were specified

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on failure mode and repairability, and they were analyzed with one-way ANOVA, χ^2-test, and linear regression analysis in SPSS (α=0.05).

Results: There was no significant difference in fracture strength and failure mode between all groups. Endocrown restorations on central incisors had significantly more repairable fractures than the post and core crowns. Regression analyses showed a statistically significant positive correlation between DWT/adhesive surface and fracture strength in the post and core groups.

Conclusions: Both endocrowns and post and core crowns on the central and lateral incisors obtained clinically applicable fracture strengths. In the central incisor groups, the endocrown restorations had significantly more repairable failures. When the walls were thicker, or when the adhesive surface was larger, higher fracture strengths were obtained in the post and core groups.

INTRODUCTION

Severe coronal loss of tooth tissue complicates the restoration of anterior teeth. This coronal destruction gives a higher chance of tooth fracture during function.[1] If there is a ferrule left, the tooth restoration complex is stronger.[2-4] To improve retention and fracture strength when there is less ferrule (<2 mm) on anterior teeth, post and cores are applied. The subsequent loss of tissue due to the preparation for a post weakens the root.[5-7] Metal posts were related to higher root stresses, thereby leading to irrepairable fractures.[8] Therefore, nowadays, more resilient glass fiber posts are used. The use of glass fiber posts results in mechanical characteristics more like that of dentin.[9] In a review study by Zhou and others,[8] it was shown that more often glass fiber posts led to loosening of the post instead of a fracture of the root.

With improvements in adhesive technology and controversy about the use and function of posts, an alternative treatment was offered: monoblock restorations called endocrowns.[10] When comparing posterior endocrowns to the post and core treatment, a systematic review concluded that there was no difference in fracture strength (p=0.07, n=8 articles).[11] In the last 10 years some articles have been published on the *in vivo* application of endocrowns, but the amount of clinical evidence is limited.[12-14] The type of teeth used in most articles about endocrowns are (pre)molars; there is a lack of evidence for the application of endocrowns in the anterior region. The highest bite forces (400-800 N) are found in the posterior region.[15,16] Ferrario and others[17] concluded that the maximum single tooth bite force on the central and lateral incisors was between 94-150 N (40%-48% of the maximum on molars). Little is known about the lateral forces on incisors, though on molars it was found to be around 200 N.[18,19] However, it is evident that the loading of incisors is different than that of molars.

The first publications on endocrowns in anterior teeth were with metal ceramic crowns using conventional cementation. The conclusions were mostly that there was no significant difference between post and no post.[20-22] Ramirez-Sebastia and others[23] studied the use of ceramic endocrowns using adhesive application on central incisors. This *in vitro* study concluded that endocrowns are sufficient for restoring anterior teeth with a ferrule of at least 2 mm. The recent systematic review published by Naumann and others,[24] which analysed eight articles, concluded that the ferrule effect (and maintaining cavity walls) are the most important factors in the survival of endodontically treated teeth (ETT). A recent study compared the fracture resistance of endocrowns using different preparation depths (3 and 6 mm);[25] no significant difference between the groups was found (p>0.05). Deeper preparation results in more tissue loss, and thereby the chance of perforation of the root. The remaining dentin wall thickness (DWT) could influence the survival of indirect restorations on ETT. In a systematic review of *in vitro* studies, it was recommended to use smaller post diameters to retain more DWT, which improved the fracture resistance of post-restored teeth.[26] The ability of teeth to survive forces and resist fracture is in direct positive correlation with the amount of DWT surrounding the post. In a study by Farina and others[27] on remaining DWT, the results showed that the groups with 1 and 2 mm DWT had significantly higher fracture strength values than the 0.5 mm DWT group (p<0.05). In conjunction with wall thickness, the total amount of the adhesive surface of dentin could be of influence; however, there is no evidence concerning the relation of the amount of dentin and fracture strength in endocrowns. Therefore, the objectives of this study were to compare (1) the fracture strength, (2) mode of failure, and (3) determine the possible correlation between the variables (DWT and adhesive surface), and (3) fracture strength in endocrowns and post and core crowns on central and lateral incisors. The tested null hypotheses were that there would be no significant differences in fracture strength, failure mode, and repairability between ceramic endocrowns and post and core crowns, and that there would be no significant correlation between surface/DWT on fracture strength.

METHODS AND MATERIALS

Sound human central (n=24) and lateral (n=24) maxillary incisors, free of cervical restorations and root canal treatment, were selected from a pool of recently extracted teeth. An Institutional Review Board statement of "no permission needed" was received for this study. Sound teeth with complete and straight roots, and without fractures, were included. Both central and lateral incisors were randomly divided into two groups, as shown in Table 1.

Each tooth was endodontically treated following a standard protocol under 5-7.5× magnification (OPMI pico, Zeiss, Oberkochen, Germany). An opening was made using diamond burs and was manually prepared using #15 and #20 K-Files (Dentsply Sirona, York, PA, USA). Thereafter, Ni-Ti rotary instruments (Wave-One Gold Primary 25/.07; Dentsply Sirona) were used, following the manufacturer's instructions. In between each file (hand or rotary) the canal was rinsed with sodium hypochlorite (3%). Gutta percha (Wave One Gold Primary; Dentsply Sirona) was fitted. The canal was dried using paper points, and after applying the sealant (AH-plus Jet; Dentsply Sirona) the gutta percha was applied. Gutta percha was removed until 4 mm for the central endocrown (CE) and lateral endocrown (LE) groups or 9 mm for the central post (CP) and core group and lateral post (LP) and core group, underneath the cementoenamel junction (CEJ) using hot instruments and Gates Glidden drills (Nr. 3, ø 0.9 mm; Dentsply Sirona). The pulp chamber was cleaned with alcohol and the samples were closed using Teflon tape. Following the endodontic treatment, the samples were embedded 2 to 3 mm underneath the CEJ in a self-curing PMMA (ProBase Cold; Ivoclar Vivadent, Schaan, Liechtenstein) using a mould.

The brands, types, chemical compositions, manufacturers, and batch numbers of the materials used for the study are listed in Table 2. Preparations were performed by one calibrated operator. Each tooth was reduced until 2 mm remained above the CEJ. The pulp chamber preparation of CE and LE samples was prepared tapered (to prevent undercuts for digital scanning), with an apical diameter of 1.5 mm. A chamfer was prepared, resulting in a 2-mm high and 1-mm deep ferrule (the dimensions are shown in Figure 1A). For CP and LP, the fiber post system (Rebilda; VOCO, Cuxhaven, Germany) was used without further preparation of the root canal. The smallest post (red; apical diameter, 0.5 mm; coronal diameter, 10 mm; length, 19 mm) was used for both LP and CP. Before luting the post, a chamfer of 1 mm was prepared around the ferrule (the dimensions are shown in Figure 1B). The remaining DWT of all samples was measured using a modified digital caliper (Kreator KRT705004; Varo, Lier, Belgium) at 12 places, as noted in Figure 2. The DWT was divided into three categories: incisal, cervical, and outline for analysis. In each category four measurements (mesial, buccal, distal, and palatal) were made per sample. This led to 12 measurements per sample.

Immediately after preparation and measurements, immediate dental sealing (IDS) was applied on all exposed dentin. The preparation was etched for 15 seconds with 35% phosphoric acid (Ultra-etch; Ultradent, South Jordan, UT, USA), following 15 seconds of water rinsing and air drying for 3 seconds. Optibond FL Primer (Kerr Dental, Orange, CA, USA) was applied for 15 seconds using a microbrush and air dried for 15 seconds. Optibond FL Adhesive (Kerr Dental) was applied, the excess removed, and light-cured for 20 seconds (>1000 mW/cm^2, Bluephase 20i; Ivoclar Vivadent). The irradiant light was polywave and was measured before use in this study.

After preparation, the posts of the post core groups were placed. The post was cut to the right length (15 mm, 4 mm above preparation) using a diamond bur, cleaned with 70% alcohol, and silanized using Ceramic Bond (VOCO). Debris was removed from the inside of the root canal with 70% alcohol, rinsed with water, and dried with air and paper points. The root canal was etched for 15 seconds using 35% phosphoric acid (Ultra-etch), followed by 15 seconds of water rinsing. The root canal was dried using paper points and Optibond FL Primer (Kerr Dental) was applied for 15 seconds. Optibond FL Adhesive (Kerr Dental) was applied, the surplus removed, and light cured for 20 seconds (>1000 mW/cm^2, Bluephase 20i; Ivoclar Vivadent). Rebilda DC Core (Quickmix Syringe; VOCO) was applied to the bottom of the root canal and the post was inserted. Surplus cement was removed and photopolymerized for 40 seconds. Core build-up was done with Clearfil AP-X

Table 1: *Description of the Study Groups*

Abbreviation	**Description**
LE	Lateral, 6-mm deep endocrowns
CE	Central, 6-mm deep ceramic endocrowns
LP	Lateral, 11-mm post, composite core, ceramic crown
CP	Central, 11-mm post, composite core, ceramic crown

Abbreviations: CE, central endocrown; CP, central post endocrown; LE, lateral endocrown; LP, lateral post endocrown.

Table 2: *Brands, Types, Chemical Compositions, Manufacturers, and Batch Numbers of the Materials Used for the Experiments*

Brands/Type	Chemical Composition	Manufacturer	Batch Number
Phosphoric etch	38% H_3PO_4 (phosphoric acid)	Ultradent	BFCVX BFKSJ
Prime	HEMA, GPDM, PAMM, ethanol, water, photo initiator	Kavo Kerr	5638300
Adhesive	TEGDMA, UDMA, GPDM, HEMA, bis-GMA, filler, photo initiator	Kavo Kerr	
Fiber post	Solid composite of glass fibers, inorganic fillers, and polydimethacrylates	VOCO	1809049 1812391 1723008
Ceramic Bond	Mixture of ingredients with >50% acetone	VOCO	1748245
Dual cure resin cement	Bis-GMA 2.5%–5%, UDMA 10%–25%, DDDMA 5%–10%	VOCO	1802340
Light cure composite	Bis-GMA, TEGDMA, silanated barium glass filler, silanated silica filler and colloidal silica, dl-Camphorquinone, catalysts, accelerators, pigments	Kuraray Noritake	AT0722
Silica coating particles	Aluminium trioxide particles coated with silica (particle size 30 μm)	3M ESPE	
Ceramic etching gel	9% hydrofluoric acid	Ultradent	B9QRL
Silane coupling agent	Ethanol, 3-(trimethoxysilyl)propyl-2-methyl-2-propenoic acid	Bisco	1800002460
Silane coupling agent	Ethanol, 3-trimethoxysilsylpropylmethacrylaat, methacrylated phosphoric acid ester	Ivoclar Vivadent	
Light curing composite	1,4-Butandioldimethacrylate, urethandimethacrylate, diurethandimethacrylate, iso-propyliden-bis (2(3)-hydroxy-3(2)-4(phenoxy) propyl)-bis(methacrylate), glass filler: mean particle size 0.7 μm; highly dispersed silicone dioxide	Micerium	2017004722
Glycerin gel	Purified water, glycerin, methylparaben, propylparaben, propylene glycol, hydroxyethylcellulose, dissodium, phosphate, sodium phosphate, tetrasodium, EDTA	Johnson & Johnson	B189231
Lithium disilicate	97% SiO_2, Al_2O_3, P_2O_5, K_2O, Na_2O, CaO, F, 3% TiO_2, pigments, water, alcohol, chloride	Ivoclar Vivadent	W45123

Abbreviations: Bis-GMA: bisphenol-glycidyl methacrylate; GPDM, glycero-phosphate dimethacrylate; HEMA, hydroxyethyl methacrylate; PAMM, phthalic acid monoethyl methacrylate; TEGDMA, triethylene glycol dimethacrylate; UDMA, urethane dimethacrylate.

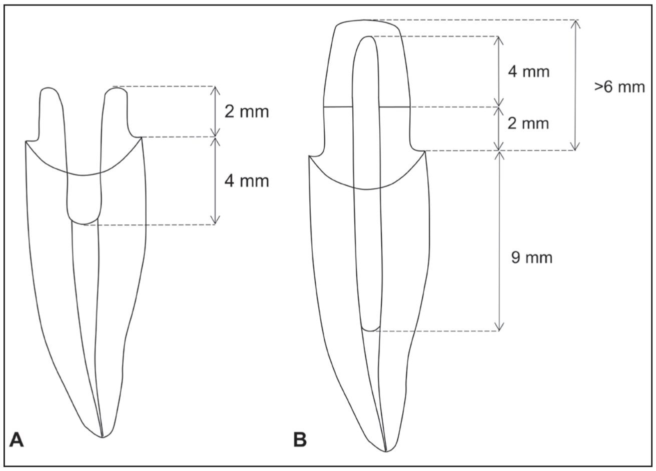

Figure 1. *Dimensions of endocrown **(A)** and post and core samples **(B)**.*

PLT A3 (Kuraray Noritake Dental Inc., Tokyo, Japan). The fiber post was completely covered with composite. The preparation was finished using diamond burs and silicone rubbers (Shofu, Kyoto, Japan).

The prepared and measured samples were then scanned with an intraoral scanner (Omnicam; Dentsply Sirona). After scanning the preparations, the crowns were designed using Cerec SW 4.4.4 software. The height dimensions of the crowns were made the same for the LE and LP samples (9 mm) as well for the CE and CP samples (11 mm). To increase the fit of the endocrowns, the designed space for the cement spacer was reduced from 120 μm to 30 μm in the Cerec software. The lithium disilicate crowns (IPS e.max; Ivoclar Vivadent) were made using the Sirona MC-XL milling unit (Dentsply Sirona). The burs used were

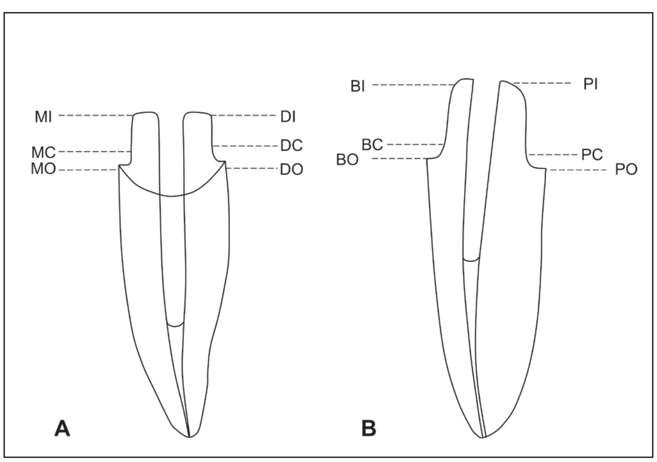

Figure 2. *Locations for 12 measurements on a mesio-distal **(A)** and buccal-palatal **(B)** cross section. Abbreviations: B, buccal; C, cervical; D, distal; I, incisal; M, mesial; O, outline P, palatal.*

Cylinder Bur 12 EF, Cylinder Pointed Bur 12 EF, Step Bur 12S, and the Cylinder Pointed Bur 12S (Dentsply Sirona). After crystallization, the crowns were glazed (IPS e.max Ceram Glaze Paste FLUO; Ivoclar Vivadent). The inner side of the crowns was analyzed for surplus of glaze paste and, if present, the surplus glaze was removed using sandblasting.

All indirect restorations were luted using a heated resin composite material (Enamel HFO UD2; Micerium, Avigno, Italy). The lithium disilicate crowns were conditioned with 9% hydrofluoric acid ceramic etch (Ultradent, Cologne, Germany) for 60 seconds, rinsed in water with neutralizing agent, and then air dried. Phosphoric acid (35%, Ultra-etch; Ultradent) was applied for 1 minute to clean the gross amount of glass particles on the intaglio, and after rinsing the crowns they were ultrasonically cleaned (Emag, Valkenswaard, The Netherlands) in distilled water for 5 minutes. The crowns were then silanized (Monobond Plus, Ivoclar Vivadent) and after 60 seconds were heat dried at 100°C (DI500; Coltene, Altstatten, Switzerland) for 5 minutes, then adhesive resin was applied (Optibond FL Adhesive; Kerr Dental). The teeth (IDS layer and composite build-up) were conditioned with 2 to 3 seconds of silica coating (3M ESPE, St. Paul, MN, USA), following silanization (Bis-Silane, Bisco, Schaumburg, IL, USA) and dried for 5 minutes. Adhesive (Optibond FL; Kerr Dental) was applied to the teeth and heated (55°C, ENA heat; Micerium) composite (Enamel HFO UD2; Micerium) was placed to the preparation. All lithium disilicate restorations were luted by finger pressure until they were completely seated. Excess composite was removed using a probe, and afterwards each side was photopolymerized for 40 seconds (>1000 mW/cm^2, Bluephase 20i; Ivoclar Vivadent). Glycerine gel (K-Y; Johnson & Johnson, Sezanne, France) was applied and again photopolymerized for 40 seconds on the 4 sides. The surplus photopolymerized composite was removed using a scaler (H6/H7; Hu-Friedy, Chicago, IL, USA) and the margins were polished using Ceragloss green (Edenta AG, Austria, Switzerland).

Aging was performed using thermocycling (Willytec, Munich, Germany): 10,000 times in baths of 5°C and 55°C, with a dwell time of 30 seconds. Fracture load was performed in a universal testing machine (MTS 810; MTS, Eden Prairie, MN, USA) using a stainless steel bar at 135° to imitate the oral situation, as shown in Figure 3. The samples were stored in water until fracture but were tested in a dry environment. The load was applied on the incisal edge with a crosshead speed of 1 mm per minute. The teeth were loaded until fracture, and the maximum fracture strength was used for the analysis. Failure modes were analyzed for and

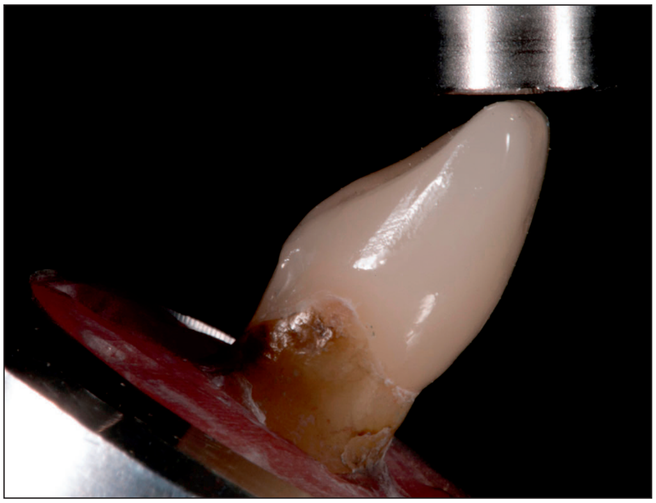

Figure 3. *Sample in universal testing machine at 135° for fracture load test. Force applied until fracture by stainless steel rod (1 mm/minute).*

categorized by: (1) cohesive failure in the material of the indirect restoration; (2) adhesive failure between the indirect restoration material and the dentin; (3) adhesive failure between the build-up and the crown; (4) loosening of the post and core and the crown; (5) cohesive failure in dentin; and (6) the fracture extending to the root. After this, all failures were classified as repairable or irreparable. Fractures more than 1 mm under the CEJ and extending into the root dentin were classified as irreparable.

The number of samples were calculated with a power analysis using G*Power 3.1 (effect size = 0.5, power = 0.8, significance level = 0.05).[28,29] The surface area (mm^2) of the preparations was determined using Geomagic (Control TM 2014, 64 bit). Data was analyzed using a statistical software program (SPSS 24.0; SPSS Inc., Chicago, IL, USA). One-way analysis of variance (ANOVA) was used to analyze the fracture strength results. A χ^2-test was performed to analyze the differences in the mode of fracture and repairability between the different groups. A linear regression analysis was executed to analyze the influence of adhesive surface and remaining DWT on fracture strength.

RESULTS

The results of the fracture load test are presented in Table 3. One-way ANOVA was calculated on the fracture strengths. The analysis was not significant: F (3, 44)=1.20, p=0.319. There was no statistically significant difference in fracture strength between the groups, independent of the outlier (Figure 4). Analyzing the mode of failure (Figure 5) with a χ^2-test did not result in statistical significance: χ^2 (9, n=48)=11.54, p=0.240.

Table 3: *Results of Load to Fracture Test (N)*

	Mean	Standard Deviation	Minimum	Maximum
CP	319.9	139.9	101.4	517.3
LP	267.8	115.1	132.1	474.7
CE	258.3	102.9	108.5	524.7
LE	240.9	50.5	170.0	318.2

Abbreviations: CE, central endocrown; CP, central post and core; LE, lateral endocrown; LP, lateral post and core; N, newton.

There was no statistically significant difference found in failure mode. Most of the samples (>90%) had fractures extending into the root.

If repairability is considered, the LP, CP, and core groups all had irreparable fractures. In the CE group, 5/12 were repairable and in the LE group 1/12 was repairable. The χ^2 analysis was significant: χ^2 (3, n=48)=12.99, p=0.005. Only the analysis of CE (42% repairable) and CP (0% repairable) was statistically significant. Post and core crowns on central incisors had more irreparable fractures (χ^2 [1, n=24]=8,263, p= 0.004), which made extraction necessary. The LE group (8% repairable) was not significantly different from the LP group (0% repairable). Figure 6 shows a repairable endocrown sample (Figure 6A), an irreparable endocrown sample (Figure 6B), and an irreparable post and core sample (Figure 6C).

To determine the possible relation between adhesive surface/DWT and fracture strength, a linear regression analysis was calculated. In the endocrown groups (CE and LE), a nonsignificant regression equation was found (F 4, 19)=1.130, p = 0.372), with an R^2 of 0.192. There was no statistically significant correlation between DWT and fracture strength, nor between the adhesive surface

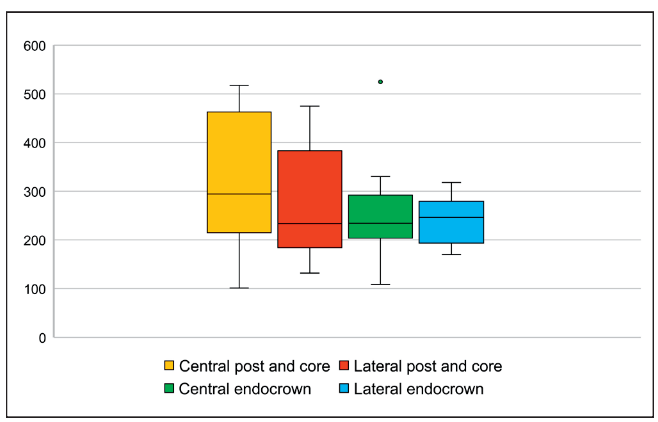

Figure 4. *Fracture strength. Mean ± 1 standard deviation. Means are not significantly different (p=0.319). °=outlier.*

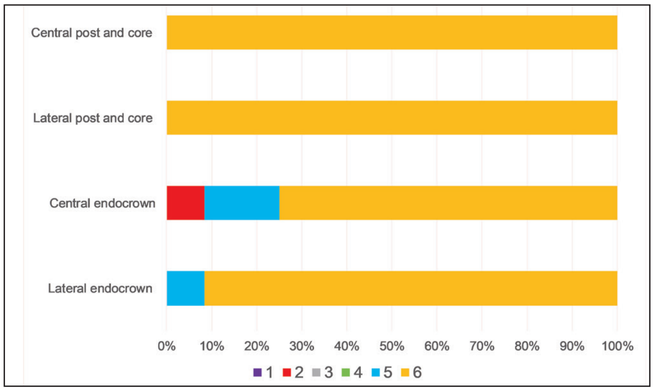

Figure 5. *Frequency of failure mode: cohesive failure in the material of the indirect restoration (1); adhesive failure between the indirect restoration material and the dentin (2); adhesive failure between the build-up and the crown (3); loosening of the post and core crown (4); cohesive failure in dentin (5); and fracture extending to the root (6).*

and fracture strength. In the post and core groups (CP and LP), a significant regression equation was found F (1.22)=19.086, $p<0.000$), with an R^2 of 0.465. There is a statistically significant correlation between DWT and fracture strength, just as there is between adhesive surface and fracture strength. There were positive equations (Table 4), as, for example, the equation between cervical DWT and fracture strength: fracture strength = -118.302 + 244*cervical DWT. For each mm of cervical DWT, the fracture strength increased with 244 N. In Figure 7, the trendline for cervical DWT and fracture strength is shown. Trendlines for surface, cervical, and incisal DWT and fracture strength were comparable.

DISCUSSION

Restoration of severely damaged anterior teeth depends highly on the amount of remaining ferrule.[4] In such situations the use of a post with a high elastic modulus is advised.[30] Improvements in adhesive technologies have led to the suggestion of endocrown restoration.[10] A recent systematic review indicates that the performance of endocrowns may be equal to that of conventional post and core treatments; however, most of the studies

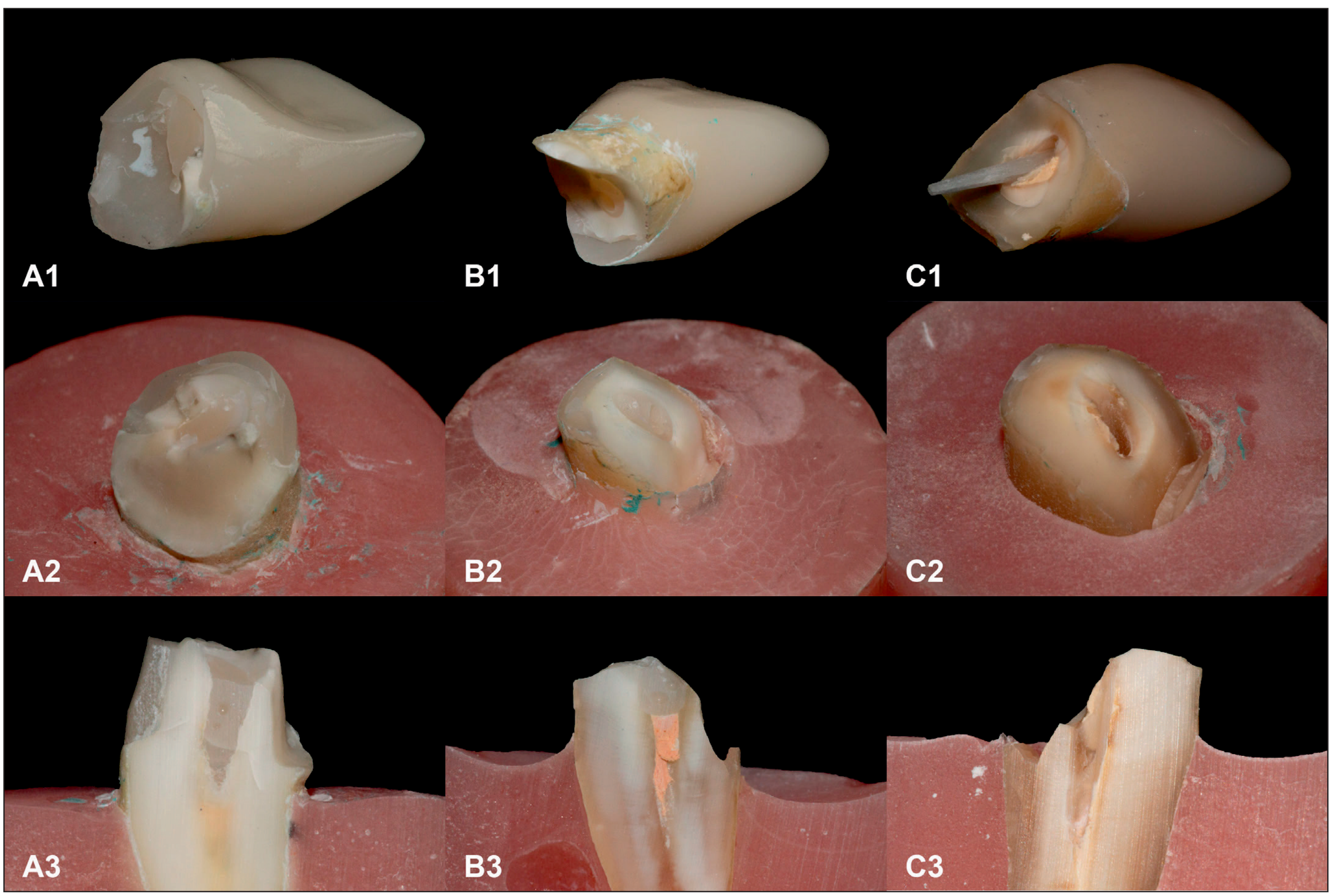

Figure 6. *Examples and cross sections of fractured samples.* ***A1-A3:*** *Repairable fractured endocrown sample.* ***B1-B3:*** *Irrepairable fracture endocrown sample.* ***C1-C3:*** *Irrepairable fractured post and core sample.*

Table 4: *Test Outcome for Linear Regression and Regression Equation Between Independent Variables (Surface and Incisal, Cervical and Radix DWT) and the Dependent Variable (Fracture Strength)*

Correlation	Test Outcome	Regression Equation
Incisal DWT/fracture strength	F (1,22) = 14.51, p=0.001; R^2 of 0.397	Fracture strength (N) = 208.88 x incisal DWT (mm) + 25.71
Cervical DWT/fracture strength	F (1,22) = 19.086, p<0.000); R^2 of 0.465	Fracture strength (N) = 244 x cervical DWT (mm) - 118.30
Radix DWT/fracture strength	F (1,22) = 18.81, p<0.000; R^2 of 0.439	Fracture strength (N) = 229.00 x radix DWT (mm) -281.44
Surface/fracture strength	F (1,22) = 18.471, p<0.000; R^2 of 0.466	Fracture strength (N) = 3.38 x surface (mm^2) -43.76

All correlations are significant (p<0.05). Abbreviations: DWT, dentin wall thickness; mm, millimeter; N= newton.

on endocrown restorations have been done on posterior teeth.[11] If anterior teeth are studied, central incisors are chosen,[23,25,31] or bovine teeth are used;[2,3] there are no studies that include human maxillary lateral incisors. Therefore, the objectives of this study were to compare fracture strength and mode of failure, and determine the possible correlation of DWT/adhesive surface and fracture strength in endocrowns and post and core crowns on central and lateral incisors.

According to the results of this study, the first hypothesis, which states that there is no significant difference in fracture strength could be accepted as the fracture strength in all groups were not statistically different; however, the fracture strength is comparable with other studies on ETT, which were done on central incisors.[3,31] More importantly, all mean fracture strength results obtained in this study (>240 N) exceeded the

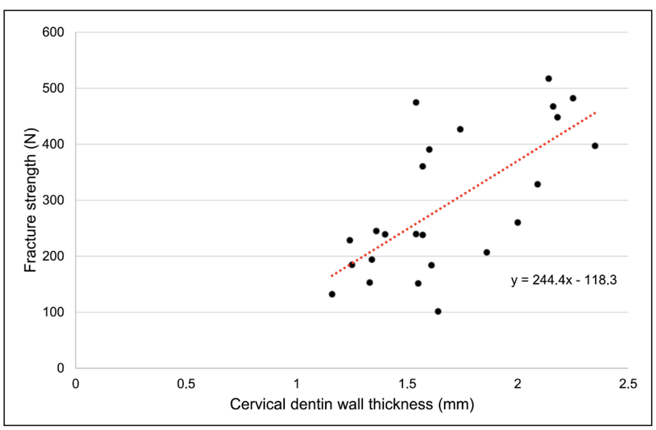

Figure 7. *Statistically significant correlation equation between cervical DWT and fracture strength for post and core samples. y=fracture strength (N), x=cervical DWT. Abbreviation: DWT: dentin wall thickness.*

clinical bite forces of 93 and 150 N.[17] Considering fracture strength, both endocrown and post and core crown restorations should be applicable in a clinical situation.

Besides fracture strength, failure mode and repairability are also important. Considering failure mode, the second hypothesis could be accepted: there is no significant difference in failure mode. The mode of failure and being not significantly different between the groups is in accordance with the majority of studies done on this topic.[2,3,23] One study recorded more root fractures in endocrowns than in post and core crowns.[31] In comparison with studies on posterior teeth, the same nonsignificant results were found.[32,33]

There was a significant difference (p<0.05) in clinical repairability between endocrowns and post and core crowns on central incisors in this study. Despite the similar failure modes, the endocrowns obtained more repairable failures. Therefore, the third hypothesis, stating that there is no difference in repairability, could be partially rejected, as there is a statistically significant difference in repairability between both restorations. Fractures observed in the endocrown groups were more horizontally oriented (Figure 6A), whereas the post and core crowns had more vertical root fractures (Figure 6C). Most of the endocrown samples broke in the upper part of the tooth together with the intrapulpal extension so the root remained intact (Figure 6A2). The small dimensions of this extension, which could be a disadvantage for its retention, here shows to be an advantage. Other research on repairability is inconsistent: There is a study that states that central incisors restored with-posts causes less fractures, but they compared a fiber post against no extension into the root canal.[34] Von Stein and others[35] reported no significant difference between post and no-post, and both were repairable in 60% to 90% of specimens. Magne and others[3] studied the application of endocrowns on bovine incisors and found better repairability of endocrowns. They found 100% irreparable fractures in post and core crowns and 47% repairable fractures in endocrowns. The inconsistency in the literature is probably explained by the inconsistencies in the methodologies and study designs. The depth of posts, the design of no-post groups, and the materials used could have had an impact on fracture behavior. Posts are longer than the intrapulpal extension used in this study. Post and core crown samples caused fractures that extended further into the root than the endocrown samples caused. The shorter the extension, the smaller the fracture. The extension length should be balanced between macromechanical retention and the prevention of root fractures. In posterior teeth, additional studies found no difference in repairability between conventional (post-core) and endocrowns.[32,33,36]

There was a statistically positive correlation between the variables, DWT and surface, and fracture strength in the post and core crown samples. The fourth hypothesis, concerning the correlation between surface/DWT and fracture strength, can therefore be partially rejected. There was a significant positive correlation between both adhesive surface/DWT and fracture strength in the post and core crown restorations. When the walls were thicker, or the adhesive surface larger, higher fracture strengths were obtained. This correlation could also explain the difference in standard deviation for fracture strength between the post and core crown groups and the endocrown groups. Varying dimensions of the post and core crown samples determine the fracture strength and contribute to a higher standard deviation. The increase in fracture strength correlated to DWT was also found in other studies.[27,37] A significant difference was found between the 2 mm and 1 mm groups and the 0.5 mm remaining dentin wall groups.[27] The same findings were found on long posts (12 mm).[37] One study found no significant difference between 1- and 2-mm thick roots.[38] However, the failure mode is always significantly different and more destructive in samples with less DWT.[37,38] In all these studies, bovine teeth[37] or human canines[27,38] are used, and there are no studies considering DWT on human upper incisors. Due to the correlation found, it could be stated that the smaller the teeth, the less favorable a post placement becomes: The fracture strength decreases, and the failure mode seems to become more destructive. This tendency was not found in the endocrown groups.

A possible limitation of this study is the deficiency of the initial dimension measurement and the high variance in fracture strength, and, therefore, the low power of one-way ANOVA considering the fracture strength. Due to the variety in tooth dimensions there is a higher standard deviation in fracture strength. The estimated power of the one-way ANOVA is 0.3. This low power is a consequence of the study design in which the DWT is of interest and another test (regression analysis) was performed. If a stricter inclusion protocol on the size of teeth was used, the influence of DWT would be difficult to study. Because of the variance in tooth dimension, there was a variance in DWT after preparation, which led to variation in fracture strength (shown as significant regressions). There was no Weibull analysis performed based on the disadvantages of the restricted sample size and the diversity of materials noted by Quinn & Quinn.[39]

Based on a study by Marchionatti and others,[40] no simulation of periodontal ligament (PDL) was used in this study. They studied the influence of PDL on teeth restored with fiber posts, comparable with the current study and found no significant difference in fracture strength. Therefore, the use of a PDL was not applied, comparable with many articles on this subject.[2,23,31,36,41] If there was an impact on fracture strength: it was standardized for all groups.

The computer-aided design/computer-aided manufacturing (CAD/CAM) fabrication of the restorations was another limitation in this study, and probably also in a clinical situation. The goal of an endocrown is to create more macromechanical retention due to the intrapulpal extension, thereby obtaining higher fracture strength. In this study, the scanner wasn't able to properly detect the intrapulpal preparation for the endocrown samples; the software and milling unit could not design and mill the intrapulpal extension for a perfect fit with the cavity and increasing macromechanical retention. This led to a loose fit of the crowns on the preparations. These disadvantages of CAD/CAM are not found in earlier studies. One study used CAD/CAM, but on bovine teeth, which are larger and easier to scan.[2] Another study used a different preparation design and scanning method.[25] Taking the preparation, intraoral scanner, and milling unit used in this study in consideration, a better method to fabricate the restorations would be conventional impressions and using pressed ceramics. Next to that, multiple studies on the internal fit of ceramic crowns state that the fit of heat-pressed crowns is better than CAD/CAM milled crowns.[42-44] The tools of conventional impressions should be researched in future studies.

CONCLUSIONS

1. Endocrowns and post and core crowns on central and lateral incisors had no statistically different fracture strengths.
2. The endocrown restorations had significantly more repairable failures than the post and core crowns in the central incisor groups.

There was a positive correlation between DWT and the fracture strength in the post and core crowns. When the walls were thicker or the adhesive surface larger, higher fracture strengths were obtained. For the endocrown groups these correlations were not found.

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Conflict of Interest

The authors of this article certify that they 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.

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