

ORIGINAL ARTICLE

Effect of incomplete crown ferrules on load capacity of endodontically treated maxillary incisors restored with fiber posts, composite build-ups, and all-ceramic crowns: An *in vitro* evaluation after chewing simulation

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Abstract

Objective. The aim of this study was to compare the fracture resistance of endodontically treated maxillary central incisors with incomplete crown ferrules after chewing simulation. **Material and methods.** Forty caries-free maxillary central incisors were divided into 4 groups ($n = 10$). Endodontic treatment was performed. Teeth were decoronated 2 mm above the cemento-enamel junction (CEJ). Group I (control) provided a 360° circumferential 2-mm ferrule. In group II, a 2-mm ferrule was present on the palatal aspect (status after occlusal overload), and in group III on the facial aspect (status after traumatic injury). In group IV, the ferrule was interrupted by bi-proximal cavitations (simulating caries treatment). The teeth received glass fiber reinforced posts and composite core restorations. All-ceramic crowns were adhesively cemented. Specimens were simultaneously exposed to thermal cycling and mechanical loading (1.2 million cycles; 6,000 cycles 5°/55°C) and finally statically loaded until failure in a universal testing machine (crosshead speed = 1 mm/min). For statistical analysis, the Kruskal-Wallis test was applied followed by the Mann-Whitney U-test as post hoc testing. **Results.** The median fracture load values (min./max.) were: group I = 502 (326/561), group II = 658 (280/827), group III = 899 (396/1176), and group IV = 360 (279/646). Analysis revealed statistically significant differences between test groups, except between groups I and IV and groups II and IV. **Conclusions.** The fracture resistance of endodontically and post/core restored teeth is dependent on the degree of tooth conservation. An incomplete crown ferrule is associated with greater variation in load capacity and, despite high fracture values, inclines to fracture.

Key Words: Ferrule effect, fracture load, post and core

Introduction

While substantial hard tissue loss by decay, endodontic, or restorative procedures means a high risk for tooth fracture of endodontically treated teeth, the loss of moisture and increasing brittleness can be excluded [1–4]. The role of a dental ferrule, an embracement of the hard tissue by crown restoration of a certain height, is mandatory for a post-endodontic reconstruction of severely damaged teeth. A dental ferrule preparation combines a shoulder preparation with parallel coronal dentin walls. The tooth tissue is enclosed by the crown improving the overall resistance of the restoration [5]. The “ferrule effect” reduces the wedging of tapered posts or bending forces during post-insertion and helps to

improve the marginal integrity of fixed partial dentures [6]. Based on *in vitro* testing, the recommended ferrule height ranges from 1.5 to 2 mm [7–9]. To provide an adequate clinical crown length with a proper ferrule height, orthodontic extrusion or crown lengthening has been suggested [6,10]. Tooth resistance is not improved by a ferrule when thin root canal walls of excessively flared teeth are present [11].

Under clinical conditions, maxillary incisors are often centrally or laterally damaged [12]. Occlusal overload causes a fracture from palatal to cervical, often at a sub-gingival level on the facial side of the tooth. Traumatic injury results in coronal fracture on the facial side, which extends to the cervical-palatal side. Often, proximal cavities were found which leave

hard tooth tissue only on the facial and palatal side. In such cases, a favorable 2-mm deep proximal ferrule is difficult to achieve. The question arises as to what extent the degree of dentin preservation influences the success of the ferruled anterior restoration.

Our objective was to compare a 2-mm circumferentially complete crown ferrule control (group I) with others missing a facial (group II), palatal (group III), or mesial and distal (group IV) ferrule segment. The fracture resistance of post-retained post-endodontic all-ceramic crowns was evaluated after a 5-year use simulated by an *in vitro* standard preclinical risk evaluation of materials or techniques with thermal cycling and mechanical loading (TCML) [13,14]. The null hypothesis was that there is no difference between the fracture resistances of the four types of restoration.

Material and methods

The method of specimen preparation and loading was adopted from Butz et al. (15). Forty caries-free, undamaged human maxillary central incisors were divided into 4 groups (group size of $n=10$) on the basis of cervical size. To ensure an even distribution of the size of teeth within the specimen groups, mesio-distal (MD) and facial-lingual (FL) dimensions were measured at the level of the cemento-enamel junction (CEJ). A size assessment value was calculated from the product of $MD \times FL$. Teeth of extreme size were excluded and specimens were randomly distributed into test groups (Table I). All teeth were stored at room temperature in a 0.1% thymol solution. Root canals were enlarged to size 60 (Antaeos, VDW, Munich, Germany) and rinsed with 2.5% sodium hypochlorite. Root canal filling was done by lateral condensation with gutta-percha (Roeko, Langenau, Germany) and a sealer (AH 26; De Trey, Constance, Germany). The clinical crowns were cut 2 mm coronal to the most incisal point of the proximal CEJ.

Preparation of the specimens was done step-by-step, starting from a circumferential ferrule of 2 mm (group I) for every specimen, subsequently reducing hard tissue facially or palatally, according to the aimed design. Group II hard tissue was removed on the facial side of the teeth, providing a 2-mm ferrule only on the palatal side. Conversely, all group III teeth had the palatal hard tissue removed. Bi-

proximal cavitations were prepared on teeth in group IV, where the circumferential ferrule was interrupted by means of a round bur with a 1.2-mm diameter (Figure 1).

Gutta-percha was removed (Gates-Glidden burs) leaving 4 mm or more in the apical portion. The root canal was prepared with a tapered drill of 1.4-mm maximum diameter (Fiberpoints Root Pins post kit; Schütz-Dental, Rosbach, Germany) to achieve an intraradicular post length of 8 mm. The root canals and the tooth surfaces were cleaned with an air-particle abrasion system (DentoPrep™, Aluminium Oxide Microblaster; Rønvig, Denmark and Cojet™, 3M ESPE, Seefeld, Germany). Glass fiber posts (Fiberpoints Root Pins Glass, diameter 1.4 mm, length 13 mm; Schütz-Dental) were luted with a self-adhesive resin cement (RelyX Unicem, 3M ESPE) and light activated for 2 s (Optilux light curing unit; Demetron Research Corp., Danbury, USA). Excess luting material was removed. Final light curing was performed for 1 min. Afterwards, composite cores (NewBond, Kuraray Europe, Düsseldorf, Germany; Clearfil Core, Kuraray Europe) were built up. All teeth were prepared with a circumferential 1.2-mm shoulder to meet all-ceramic crown requirements.

In areas without ferrule design, the preparation ended directly below build-up material in dentin. With the help of a silicone mold, 40 similar crowns were fabricated from an all-ceramic material (Empress II; Ivoclar-Vivadent, Schaan, Liechtenstein). The crowns were adhesively luted with RelyX Unicem (3M ESPE) in accordance with the manufacturer's instructions. All roots were blocked out with wax 2 mm below the finish line to imitate biologic width. To simulate a human periodontium, the roots of the teeth were covered with a 0.1-mm-thick layer of autopolymerizing silicone (Anti-Rutsch-Lack; Wenko, Wensselaer, Germany) [15,16]. The teeth were embedded in autopolymerizing acrylic resin (Technovit 4000, Kulzer, Wehrheim, Germany) orienting their long axes facially 135° from the horizontal (Figure 2). To prevent overheating, the teeth were submerged in water for 5 min during resin polymerization.

A 5-year period of service was simulated by thermal cycling and mechanical loading (TCML) performed on eight specimens from each group [parameters: 6,000 thermal cycles (5°C/55°C, 2 min each cycle, H₂O dist.) and 1.2×10^6 mastic-

Table I. Values of root size and length and results of load testing

Test group	Ferrule design	<i>n</i>	Root length [mm] median (min./max.)	Root size [mm ²] median (min./max.)	Fracture load F_{\max} [N] median (min./max.)
I	Circumferential	8	19.0 (11.3/22.6)	52.3 (44.2/58.5)	502 (326/561)
II	Palatal only	7	19.3 (15.9/21.2)	53.0 (44.9/57.8)	658 (280/827)
III	Facial only	7	18.7 (15.5/21.7)	50.3 (45.5/58.5)	899 (396/1176)
IV	Facial-palatal	5	16.4 (15.4/19.8)	48.3 (46.9/57.7)	360 (279/646)

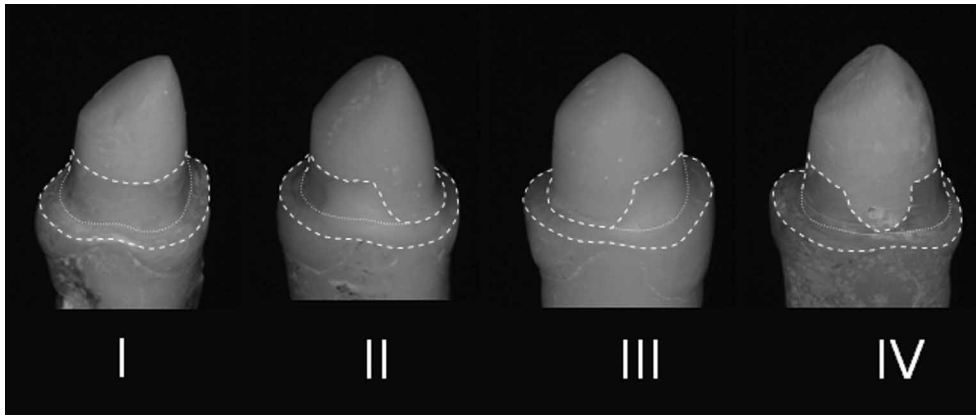


Figure 1. Ferrule preparation of specimens of experimental groups (left site of each specimen = palatal aspect).

tion cycles at an angle of 135° as described above [17]. A 50N force was applied 3 mm below the incisal edge on the palatal surface of the crown (Figure 2). After TCML, the specimens were loaded in a universal testing machine (Zwick, Germany; crosshead speed of 1 mm/min) until fracture occurred. Failure detection was set at a 10% loss of the maximum applied force. To reduce excessive stress concentrations, a 0.3-mm-thick tin foil was positioned between the steel piston and the lingual surface of the crown. As a TCML control, two randomly chosen specimens of each group were loaded in a universal testing machine without TCML. Fracture load and fracture patterns were recorded for all teeth.

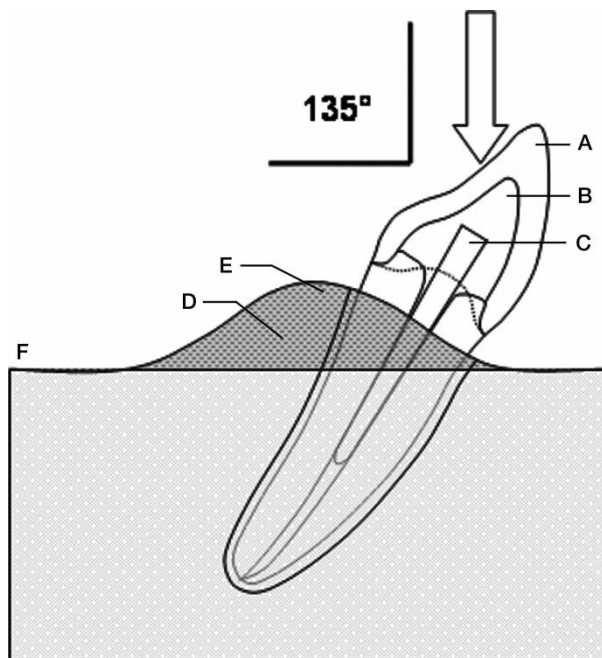


Figure 2. Experimental design of chewing simulation and static load testing: (A) all-ceramic crown, (B) composite core build-up, (C) post, (D) acrylic resin mounting specimen, (E) simulated periodontal ligament, (F) specimen holder.

A non-parametric Kruskal-Wallis test was applied followed by the Mann-Whitney U-test as post hoc testing to study statistical differences in the maximum load capacity F_{\max} between the groups. All tests were two-sided. Significance was set at $\alpha = 0.05$.

Results

The results of load testing are presented in Figure 3. The highest median fracture results were found for the facial ferrule design (899N). The circumferential ferrule had a median of 502N and the palatal ferrule of 658N. The facial-palatal ferrule design showed the lowest fracture results (360N). One specimen each of the palatal and facial ferrule group, as well as three specimens of the facial-palatal ferrule group, failed during TCML.

Specimens which did not survive TCML were excluded from the statistical analysis. The F_{\max} values tested by the Kruskal-Wallis test showed statistically significant differences ($p = 0.005$). Post hoc analysis with the Mann-Whitney test revealed statistically significant differences between groups I and II ($p = 0.021$), I and III ($p = 0.014$), II and III ($p = 0.038$), and III and IV ($p = 0.01$). No statistically significant correlation was found between groups I and IV ($p = 0.524$) or between II and IV ($p = 0.073$). Median, minimum, and maximum values of the fracture results are presented in Table I. The specimens without TCML showed fracture results of 471N and 517N for group I, 379N and 642N for group II, 656N and 1064N for group III, and 352N and 437N for group IV.

The most frequent type of failure was an oblique fracture from the palatal CEJ to the border of the second and third quarters of the root on the facial surface. Four additional horizontal root fractures close to the level of the post-tip were observed solely in the control group. The fracture modes are presented in Figure 4. All fracture patterns were judged as catastrophic and irreparable.

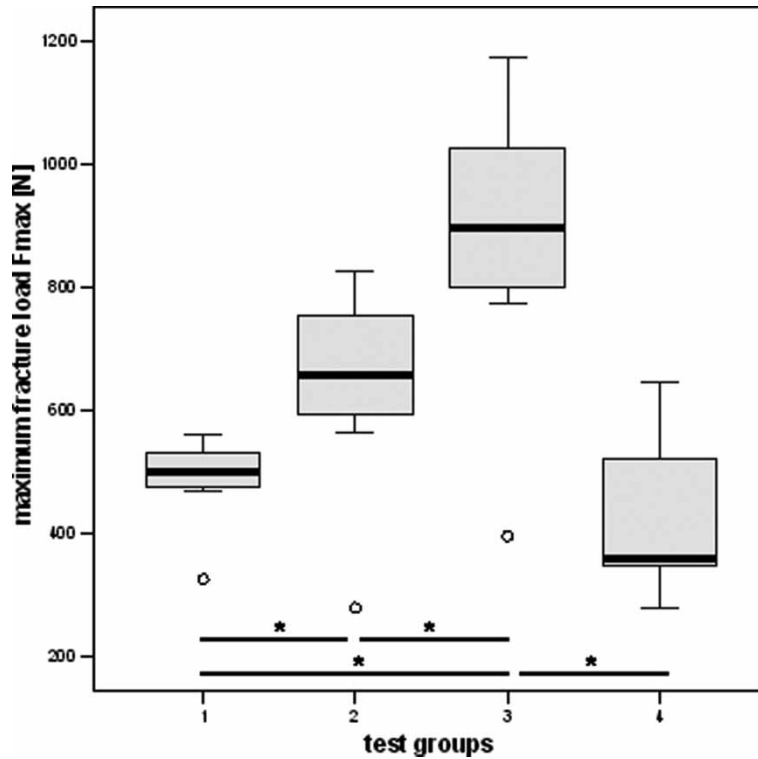


Figure 3. Box plots displaying fracture loads, thick bars for median failure load; thin bars for lowest and highest values (* $p < 0.05$).

Discussion

Clinical experience shows that tooth fracture often follows patterns. Occlusal overload may cause facial sub-gingival tooth damage and leave palatal hard tissue intact. Perpendicular loading to the facial surface commonly results in a palatal sub-gingival level fracture.

The present investigation was a study of the influence of three preparation designs on the fracture resistance of incomplete 2-mm crown ferrules compared to a continuous 2-mm crown ferrule. Eight

specimens per group were exposed to TCML and loaded until fracture. It was indicated that a continuous 360°, 2-mm ferrule resulted in a lower failure load capacity after TCML than test groups with a palatally or facially limited ferrule. All specimens with a circumferential ferrule survived chewing simulation. One specimen of each group failed when only a palatal or a facial ferrule was present. Three specimens without a mesial and distal ferrule already failed during simulation and the remaining specimens revealed the lowest fracture load values. With

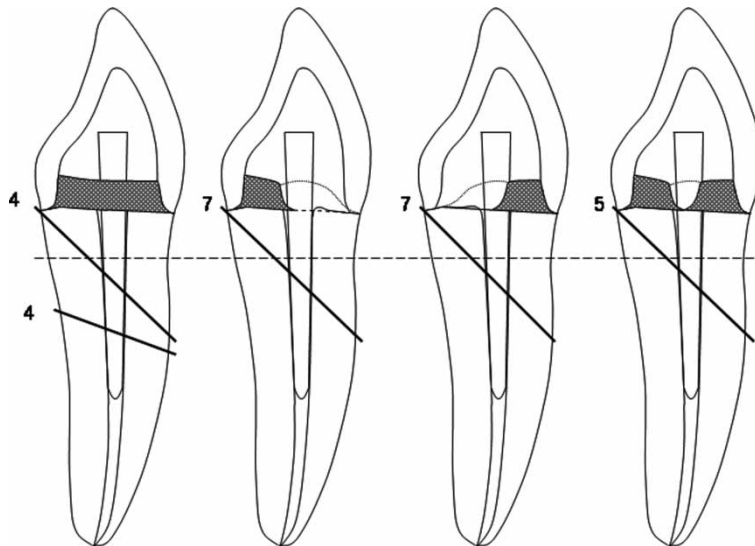


Figure 4. Fracture patterns and frequencies associated with all groups tested; one specimen each in groups II and III and three specimens in group IV are not included because of early failure during TCML. Thin line marks border of failures judged as catastrophic (tooth not restorable).

the exception of group IV, the median values exceeded the level of 400N and thus the load expected clinically [18,19]. A small distribution of the fracture results was obvious for the group with a complete ferrule.

Since it is generally accepted that the amount of remaining hard tissue is crucial for load capability or restoration, one might favor a circumferential ferrule. A specimen with a proximal interrupted ferrule provides more hard tissue than restorations with a facial or palatal ferrule remnant. Both groups might be expected to behave similarly and inferior to the proximal interrupted ferrule group. The adhesive area for the core built-up of group I is the smallest and might explain the comparably low maximum fracture load. Teeth that were prepared with a palatal ferrule showed an enlarged adhesive area of the build-up compared to group I. Teeth with a facial ferrule provided similar adhesive surfaces, but only minimal mechanical support due to the small remaining dentin wall. The results of the teeth without proximal ferrule are unexpected, and might be attributed to a limited adhesion between the tooth hard substance and the composite core material.

Findings may be explainable by high amounts of horizontal forces causing tension stress on anterior teeth. Torbjorner and colleagues stated that fatigue fractures in the maxillary anterior region are caused by tension stress and not by compression. Anterior restorations are therefore considered to be highly susceptible to technical failure [20].

A palatal load on the incisal edge of an upper incisor causes tension on the palatal side and compression on the facial tooth side. The rotational axis of the tooth is situated at the crest (backbone) of the facial alveolar bone [21]. Highest loadings are found on the circumference of the root, whereas the post represents a neutral area regarding stress concentration. High stress concentrations often appear in the radicular one-third of the root [22], explaining the fracture patterns observed in the present study. The failure typically starts at the weak link between restoration and tooth, which is commonly the crown margin. There the bond strength is limited by the retentive strength of the luting material. With crown placement, stress increase is found in the area of the crown margin [22].

Technical failures of fixed prosthodontics are, as a rule, caused by fatigue fractures. Fatigue fracture occurs at the weakest point or where maximum stress occurs [23]. Hence, a primarily marginal cervical opening is expected on the palatal region. Intermittent tension causes fatigue fractures of dentin or cement [20]. If the crown retention is weakened, mastication load acts mainly on the post and core restoration. If tension or bending reach critical values, a slowly growing crack results in a typical cervical-palatal to facial-sub-gingival fracture pat-

tern. The all-ceramic crown is not directly involved in the failure procedure and therefore is not the strength-limiting factor. This typical fracture pattern was observed in all test groups. Additionally, in the group with a complete ferrule, a fracture line close to the post-tip was apparent. Both fracture types have been observed by other investigators [15,24–26] and may be related partly to high stress levels [22].

Further information can be provided by simulating the process using finite element analysis (FEA) or evaluation of the marginal integrity before and after TCML, since focusing on fracture resistance values alone may mask other important biomechanical factors.

Conclusions

Under the conditions and limits of this *in vitro* study, the absence of portions of a crown ferrule (missing facial or palatal aspects, proximal interrupted) of an endodontically treated and post/core restored tooth is associated with greater variation of failure load. Strength values might be reduced to below a clinically acceptable load bearing.

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