Fracture strength and survival rate of endodontically treated maxillary incisors with approximal cavities after restoration with different post and core systems: an in-vitro study

Guido Heydecke a,b,*, Frank Butz b, Jörg R. Strub b

aBiologic and Materials Sciences, University of Michigan, School of Dentistry, 1011 North University Avenue, Ann Arbor, MI 48109-1078, USA
bDepartment of Prosthodontics, School of Dentistry, Albert Ludwigs University, Hugstetter Str. 55, 79106 Freiburg, Germany

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Abstract

Objectives: This study compared the fracture strength and survival rate of endodontically treated crowned maxillary incisors with approximal class III cavities and different core build-ups.

Methods: Sixty-four caries free human maxillary central incisors were selected for standardized size and quality, endodontically treated and prepared with approximal cavities 3 mm in diameter. Group 1 was restored with titanium posts, group 2 received zirconia posts, in group 3 the root canal was partially filled with a hybrid composite. In the control group, only the access opening was restored. All teeth were prepared for and restored with full cast metal alloy crowns and subsequently exposed to 1.2 million cycles in a computer-controlled chewing simulator with simultaneous thermocycling. In addition, the samples were loaded until fracture in a static testing device.

Results: One specimen with composite reinforced root canal did not survive the dynamic load test. The following median fracture strengths in Newtons for the different groups were: titanium post 1038, zirconia 1057, composite resin 750, control (no post) 1171. The fracture load in group 3 (composite resin) was significantly lower ($P < 0.05$) than in the other groups.

Conclusions: The reconstruction of endodontically treated single rooted teeth with approximal cavities can be successfully performed by closure of the endodontic and additional cavities with composite. Cementation of endodontic posts offers comparable but no advantageous fracture resistance. Enlargement of the root canal space after completion of endodontic treatment should be avoided and cannot be compensated for by injection of composite resin. Less catastrophic failures were observed without post reconstruction. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: Post and core technique; Root canal therapy/adverse effects; Dental pulp devitalization/adverse effects; Incisor; Crowns; Prosthodontics; Survival rate; Fracture strength; Artificial mouth

1. Introduction

Approximal caries with involvement of the dentin is prevalent in about 25–40% of adolescents and for incisor teeth it is the most common form of caries [1–3]. In most cases, conservative treatment is successful in restoring approximal class III defects. Root canal therapy is required in such teeth when pulpal infection occurs as a result of extensive decay, resulting in a potential further loss of structural integrity in addition to existing cavities. Endodontic treatment is often followed by internal discoloration of the now pulpless tooth. If the aesthetic results are unsatisfactory or the loss of structure requires restoration of the tooth, full coverage crowns are indicated for the aesthetic and structural restoration of such teeth with multiple defects [4].

Several factors have been discussed that influence the strength of endodontically treated teeth. The loss of moisture from dentin after endodontic treatment would appear to be insignificant [5]. According to Reeh et al. [6] cavity preparation and endodontic treatment are associated with a loss of tooth structure. Cavity preparation seems to account for most of the loss in strength. Dentin collagen content is variable depending on location and may contribute to a lower fracture resistance of incisors when compared to posterior teeth [7].

While early publications have called for the stabilization of endodontically treated teeth with intra-canal posts [8], it has been demonstrated that post reinforcement is not beneficial in completely intact teeth [9–11]. In addition, endodontically treated but otherwise intact teeth without posts
Table 1
Overview of the used post and core restorations in the four groups of specimens. Number of failures and survival rates in the groups after 1.2 million cycles of chewing simulation.

<table>
<thead>
<tr>
<th>Group</th>
<th>n</th>
<th>Endodontic restoration</th>
<th>Length of endodontic restoration</th>
<th>Number of failed specimens</th>
<th>Survival (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>16</td>
<td>Titanium post</td>
<td>3 mm short of apex</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>2</td>
<td>16</td>
<td>Zirconia post</td>
<td>3 mm short of apex</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>3</td>
<td>16</td>
<td>Composite resin</td>
<td>3 mm below CEJ</td>
<td>1</td>
<td>93.8</td>
</tr>
<tr>
<td>4</td>
<td>16</td>
<td>None</td>
<td>Closure of access only</td>
<td>0</td>
<td>100</td>
</tr>
</tbody>
</table>

perform comparable or better than those restored with post and cores if used as crown abutments [12–14]. These results have been corroborated by findings reported in clinical studies [15,16].

The choice of an appropriate restoration for endodontically treated teeth is guided by strength and esthetics. The use of composite resins as a core material has enhanced the ability to reproduce the shade and translucency of natural teeth. This is especially important when all-ceramic crowns are chosen as the final restoration. The available all-ceramic post systems offer improved esthetics and are a promising alternative to conventional metal posts [17,18]. The restoration of teeth with adhesively cemented internal restorations also provides the opportunity for improved mechanical stability over conventional cemented restorations [11,19].

As previously reported, the fracture resistance of endodontically treated teeth is largely dependent on the amount of remaining dentin [6,20]. However, it is unclear at which degree of substance loss endodontic reinforcement with posts becomes necessary in incisors with typical class III defects. The aim of this study was to compare crowned endodontically treated maxillary incisors restored with either titanium posts, zirconia posts or composite resin in the root canal and teeth without any endodontic restoration.

A near clinical model was created to compare the different restorative approaches under thermo-mechanical fatigue conditions simulating clinical parameters. The null hypotheses to be tested were that there is no difference in fracture strengths and fracture patterns between the four different types of endodontic restorations after 1.2 million cycles of thermomechanical fatigue loading.

2. Materials and methods

Human maxillary central incisors were obtained directly after extraction and were stored in 0.1% thymol solution during the course of the study. Teeth with cracks, caries and fillings or roots shorter than 10 mm were discarded. Teeth were selected for the study if the variation in length was within 1 mm when compared to the mean value of 23 mm [21,22]. The 64 selected teeth were randomly divided into four blocks of 16 teeth each (Table 1).

Endodontic treatment was performed by stepwise filing with reamers and hedstrom files to ISO size 60. After intermittent rinsing with 2.5% sodium hypochloride, all roots were obturated with laterally condensed gutta percha (VDW, Munich, Germany) and a resin sealer (AH plus®, DeTrey, Konstanz, Germany). Using a ball shaped diamond bur (#801-029, Komet, Lemo, Germany) in a high-speed handpiece, standardized approximal cavities of 3 mm in diameter were prepared on the mesial and distal of each tooth (Fig. 1).

In the first two groups, the gutta percha was removed from the canals with a peeso reamer, leaving 3 mm of root canal filling in the apical portion. Subsequently, the root canals were enlarged to receive endodontic posts using a tapered drill (ISO 90) from the Komet® ER post kit. In group 1, titanium posts (ER 61L16, Komet) were used and in group 2 zirconia posts (Cerapost® 232L12, Komet) were selected (Fig. 2(a)). After cutting them to a length 1 mm short of the palatal surface, all posts were air abraded with 50 µm aluminum oxide at 2.5 bar and cleaned in alcohol. The canals were roughened with a diamond-surfaced reamer (ER 196D-090, Komet) of the same diameter as the post. All canals were conditioned with a self-etching primer (ED-Primer, Kuraray, Osaka, Japan) and the posts were cemented using a chemically cured resin cement (Panavia 21 EX®, Kuraray). To ensure isolation from air, Oxyguard II (Kuraray) was applied. After cleaning, the post and tooth surfaces were etched for 15 s with 35% phosphoric acid (Etching agent V, Kuraray), and

![Approximal cavities](image)

Fig. 1. Location and size of the prepared approximal cavities before endodontic and crown restoration.
were filled along with the approximal cavities with composite resin (Clearfil®).

In group 3, the gutta percha was removed from the root canal to 3 mm below the cemento-enamel junction (CEJ) with a round bur (H1-014, Komet) using a slow speed hand-piece (Fig. 2(b)). All dentin and enamel surfaces were etched with 35% phosphoric acid and a bonding agent (New Bond®, Kuraray) was applied. The root canal and approximal cavities were filled with composite resin (Clearfil®, Kuraray).

In the control group, the access cavity and the approximal cavities were restored with the same hybrid composite resin (Clearfil®; Fig. 2(c)).

All teeth were prepared with 1.2 mm butt shoulders with rounded inner angles at a convergence of 6°. The finish line of each preparation was at the CEJ. Using a silicon stent, 64 single tooth incisor crowns of identical dimensions were waxed and cast in a non-precious alloy (Remanium®, Mélator, Stuttgart, Germany). The crowns were cemented with a glass-ionomer cement (Ketac-Cem®, ESPE).

A typical clinical model with a facio-lingual tooth inclination of 130° and a mesio-distal angle of 2° was chosen for the fabrication of the test specimens [21]. A silicon index incorporating these angulations was used for the creation of all specimens. To simulate a periodontal membrane, all roots were covered with a 0.1 mm thick layer of self-curing silicon (Anti-Rutsch-Lack, Wenko, Wensselaer, Germany). The roots were blocked out with wax to a depth of 2 mm below the finish line to simulate the biologic width. After the removal of any excess silicon, the teeth were positioned into a specimen holder using the silicon index, and the holder was filled with self-curing acrylic resin (Technovit® 4000, Kulzer, Wehrheim, Germany; Fig. 3) [23, 24].

All 16 specimens in each group were exposed to 1.2 million cycles of thermo-mechanical fatigue in a computer-controlled chewing simulator (Willytec, München, Germany) [25, 26]. The force was applied 3 mm below the incisal edge on the palatal surface of the crowns at a frequency of 1.3 Hz [27] using a steatite ceramic ball (diameter 6 mm; Hoechst Ceramtec, Wunsiedel, Germany) [24]. A force of 30 N was chosen to simulate a load within the clinical range [28, 29]. During testing, all samples were subjected to continuous thermocycling for between 5 and 55°C for 60 s each with an intermediate pause of 12 s, maintained by a thermostatically controlled liquid circulator (Haake, Karlsruhe, Germany) [23, 24]. The number of specimens still intact after the fatigue loading was recorded and expressed as survival in percent.

All specimens that did not fracture during the dynamic loading were thereafter loaded until fracture in a universal testing machine with a crosshead speed of 2 mm/min (Zwick Z010/TN25, Ulm, Germany). Loads were applied at an angle of 130° at the incisal edge using a tin foil to ensure even stress distribution [23, 30]. The fracture loads and the mode of fracture were recorded.

For the statistical analysis of the fracture loads multiple pair-wise comparisons using the Wilcoxon-Rank test were performed. Samples that fractured during the chewing simulation were assigned the value ‘zero’ for purposes of statistical evaluation. Tooth fractures were sub-classified into repairable and catastrophic failures. The modes of fracture between the four groups were compared using the Fisher-exact test.

3. Results

3.1. Dynamic loading

All samples except one in group 3 survived the 1.2 million cycles of dynamic loading and thermocycling in the...
Fig. 4. Box plot of the fracture strengths (N) after static loading of the specimens in each of the four groups. The median fracture load in the group restored with composite resin in the root canal space was significantly lower than in the other groups ($P < 0.05$).

artificial oral environment. The fracture, which occurred during the chewing simulation, only became apparent upon removal of the sample from the chewing simulator at the end of the experiment. For this reason, no accurate information was available on the exact time at which the specimen broke. The results of the chewing simulation are presented as survival rates for each group (Table 1).

3.2. Fracture strength test

The obtained fracture loads were non-normally distributed, therefore multiple comparisons using the Wilcoxon–Rank test were performed. In the fracture strength test, the specimens from group 3 (composite resin within the root canal) exhibited significantly ($P \leq 0.05$) lower fracture strengths when compared with the other groups. The differences between the other groups were not statistically significant. The fracture loads are illustrated as a box plot in Fig. 4.

3.3. Fracture patterns

Fractures generally involved the incisal third of the tooth beneath the crown. Most fractures were oblique and extended onto the buccal root surface well below the crown margin close to the mid-root. While the titanium posts were either bent (11) or dislodged (5) from the root canals, all the zirconia posts fractured. In group 3 (composite resin within the root canal) all fractures extended slightly below the crown margin. In the control group (no endodontic restoration), all fractures involved the coronal dentin and extended slightly below the crown margin.

The Fisher-exact test indicated significant differences in the fracture mode between the four groups ($P < 0.001$). The control group (group 4) exhibited a significantly smaller number of catastrophic fractures than any of the other test groups. The groups restored with zirconia posts (group 2) and with composite resin (group 3) had less catastrophic failures than the group restored with titanium posts (group 1; Table 2).

The fracture patterns of all groups are presented in Fig. 5.

4. Discussion

A variety of endodontic posts are available to the dental practitioner for the build-up and stabilization of non-vital teeth. In this study, cylindro-conical posts were used. Some studies have reported a wedging effect attributed to tapered posts [31], while others could not demonstrate differences between parallel-sided and tapered posts [12]. To exclude any variations resulting from different post geometries, all posts in this experiment were industrially machined to identical shape and dimensions.

What is missing from the dental literature is a systematic investigation into the necessity of post stabilization in

<table>
<thead>
<tr>
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<th>Group 1</th>
<th>Group 2</th>
<th>Group 3</th>
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<tbody>
<tr>
<td>Group 2</td>
<td>0.018*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group 3</td>
<td>0.002**</td>
<td>0.722</td>
<td></td>
</tr>
<tr>
<td>Group 4</td>
<td>&lt; 0.0001***</td>
<td>0.002**</td>
<td>0.006**</td>
</tr>
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</table>
endodontically treated teeth depending on the amount of
substance loss after cavity preparation and root canal therapy.
Previous investigations have been performed on mostly
unrestored teeth without crowns or fillings [8–11,32,33].
The results from these studies demonstrated, that a stabilizing
effect of root canal posts in endodontically treated teeth which
are otherwise unrestored cannot be detected. Posts are there-
fore unnecessary under those conditions [9,10,33]. If full
crown restorations are performed, the complete removal of
intact coronal tooth substance and the replacement with a
composite or cast post and core is not a recommended option
as no significant increase in fracture load can be observed
[13,20]. Up to this point it is not known, if the restoration of
pulpless teeth with substance defects requires any kind of
stabilization. If more than 50% of the coronal portion of the
clinical crown is lost, direct core restorations using either tita-
nium or zirconia posts are suitable restorations. Cast post and
cores offer no advantages over the direct techniques [34]. In
this experiment, a scenario was selected which is frequently
encountered in everyday practice. Three-surface approximal
cavities are the most common restoration in incisors. If endo-
dontic treatment is performed, the already compromised integ-
ity of the tooth is further affected, as the cavities will be
connected by the palatal access cavity [6]. The necessity to
restore those teeth with full crowns for aesthetic and mechan-
ic considerations was a predetermined parameter in this
study.

When the experimental restorative modalities are com-
pared, no statistical differences in the fracture loads
were detected between the two post groups and the control
group without any restoration. In the titanium or zirconia
post groups, the loss of structure for the preparation of the
post space would appear to have been obviously compen-
sated for by the reinforcing effect of the bonded posts. This
is illustrated by the fact that the control group without post
reinforcement, but also without extra loss of structure due to
post space preparation exhibited a comparable fracture load.
Consequently, a stabilizing effect by using prefabricated posts
could not be demonstrated. Similar observations have been reported in the literature for unrestored teeth
[9,11], teeth with moderate preparations and veneers [35]
and teeth with complete crowns [12,13]. The lower fracture
load found in group 3 with 3 mm of bonded composite resin
in the root canal could be explained by the loss of tooth
structure, which occurred during the removal of the gutta
percha with a round bur. The preliminary failure of one
specimen from this group during the fatigue loading could
also have been triggered by this increased loss of structure.
The root canals were only prepared to size ISO 60; therefore
an enlargement with a standard bur was performed to allow
for proper placement of the composite resin without the risk
of air entrapment. Removal of the gutta percha by using a
hot plugger and reamers would have been possible and less
invasive, but placement of the composite material seemed
difficult to achieve. We concluded that the creation of a
partial post space caused an unnecessary weakening of the
specimens and should be avoided, because it could not be
compensated for by the composite resin core [11].

An important aspect of minimally invasive restorative
approaches is the preservation of the tooth in a restorable
condition after failure [14]. The groups restored with posts
exhibited significantly more catastrophic, deep oblique root
fractures, which usually render the tooth non-restorable and
require extraction. The number of catastrophic fractures was
smaller in the group restored with zirconia posts. In group 3
there were seven and in group 4 only one catastrophic root
fracture was observed, which was significantly less than in
the post groups. A root with a 'repairable' fracture theore-
tically allows the repeated restoration of the tooth by means
of crown lengthening or forced eruption and post and core
build-up. Most specimens in the control group and half of
the specimens from group 3 were repairable after failure.

The placement of a crown has been questioned when
testing endodontic restorations as this might obscure the
effects of different core build-up techniques [36,37]. There
is no doubt that a crown creates a ferrule effect and a differ-
ent load distribution when placed over a core build-up if the
margins encircle a sound dentin collar [20,38]. However,
testing after preparation but without a crown would not
reflect common clinical practice [31]. Therefore, all samples
were restored and tested with complete coverage crowns for
reasons of standardization. However, the use of all-ceramic
crowns in the group with the ceramic posts would be clinical
reality and the results may have been different and more
clinically relevant.

All teeth were prepared to an abutment height of 5 mm
above the most incisal point of the CEJ, resulting in slightly
different final tooth lengths [38,39]. As the post space
preparation finished 3 mm from the apex or the CEJ respec-
tively, variations in post lengths also resulted. Human teeth
have been commonly used for the in-vitro testing of post
restorations in other studies [36,39,40]. The main disadvan-
tage of natural teeth is the relatively large variation in size
and mechanical parameters, often resulting in large standard
deviations. Several other studies have used human teeth
within these limitations and reported meaningful results
[13,20,31,33].

Fracture load values reported in the literature for com-
parable restorative approaches are usually obtained on

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**Fig. 5. Location of the fractures in each of the four groups of specimens.**
Fractures ending above the grey line were classified as repairable.
non-fatigued specimens. The values found in this study appear to be comparable or slightly higher than those reported in other studies [9,41]. As reported in a pilot study, the influence of the fatigue loading on the fracture loads of the endodontic restorations was not statistically significant [40]. One specimen in this study was not available for the static loading test because of fracture during the chewing simulation. To account for the effect of the fatigue loading in the statistical evaluation, this specimen was included with a fracture load of '0 N' after 1.2 million cycles of simulated service. The inclusion of this specimen has increased the numerical range of results for this group and is expressed in the larger standard deviation.

Although the findings from this study are not necessarily transferable to the clinical situation, the artificial oral environment [25,42] used in this study attempted to simulate the clinical parameters of load [29,43], cycle frequency [27] and angle [21,30]. Thermocycling was performed to simulate moisture and temperature changes encountered in the mouth. The process has been shown to correlate well with clinical studies assessing the performance of restorations over 5 years. [26,44]. Clinical trials are recommended to supplement the results of this laboratory study with clinical evidence.

Within the limitations of this study, the following conclusions can be drawn:

1. The reconstruction of endodontically treated single rooted teeth with approximal cavities can be successfully performed by closure of the endodontic and additional cavities with composite. Cementation of endodontic posts offers comparable but no advantageous fracture resistance.
2. Enlargement of the root canal space after completion of endodontic treatment should be avoided and cannot be compensated for by injection of composite resin.
3. Less catastrophic failures were observed without post reconstruction. Teeth with posts more often failed in a non-restorable manner.

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