Core build-up designs
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CHAPTER 2

A Comparative \textit{in vitro} Study of the Fracture Resistance of Different Core Build-up Designs on Endodontically Treated Premolars

2.1 Abstract

\textbf{Objective.} To investigate the resistance to fracture of three crown and core designs, made with different core build-up materials on premolars, using a standardized test method.

\textbf{Materials and Methods.} The anatomic crowns were removed from six groups (n = 8) of endodontically treated, human premolars in conformity with a brass master dye, using the Celay copy-milling device. Three of these groups were provided with a core build-up without an endodontic post, a chemical-cured resin-composite (Ti-Core), a light-cured resin composite (Photo Core) and a chemical-cured glass-ionomer (Ketac-Molar); two other groups were provided with a core build-up with an endodontic post (a cast post and core, and a light-cured resin composite core with a silica-fiber post), and one group was not provided with a core. All groups were then prepared in conformity with a second master dye. This preparation ended in axial dentin, 2 mm apical from the core build-up. Thus in the sixth group (premolars without a core build-up), this preparation only affected the 2 mm axial dentin (ferrule), which resulted in a small retention area for the crown. Finally a standard crown was cemented and after 24 hours loaded until fracture in an Instron testing machine at an angle of 45°. For comparison with the standardized procedures, a seventh group (Photo Core without post) was prepared manually, with dimensions similar to the standardized groups.

\textbf{Results.} Within the standardized test set-up no significant difference in strength between the six groups could be demonstrated. Only for the hand-made Photo Core and the cast post and core the fracture load was significantly different (P = 0.01). In addition, this hand-made group displayed a larger standard deviation than the standardized groups.

\textbf{Conclusion.} Taking into consideration the fact that the maximum bite force in the premolar region is about 580 N, these tests showed that within the limitations of the standardized test set-up, where the specimens had no history of fatiguing, a core build-up without a post is an alternative for the conventional cast core. In this study, the fabrication of the standardized specimens proved to be accurate, fast and economical. This method also enables us to investigate the performance of core and crown design combinations in relationship to the amount of remaining tooth structure by using different master dies and, moreover, to reduce the standard deviation.
2.2 Introduction

Endodontically treated premolars are often restored by using endodontic posts. An endodontic post may be individually cast in association with the core, or is delivered as prefabricated post, in which case a direct restorative material (e.g., amalgam, resin-based composite, or glass-ionomer cement) is used as a core material [1-3]. In each case, the post and core are an integral part of the restoration and must meet a number of requirements. The ideal post should provide retention to the core and an adequate seal of the root canal. It should support the core in such a manner that the cemented crown does not lose its attachment and strategically transfers forces to the tooth in order to prevent premature root fracture. Unfortunately, failures of this kind of restoration are still numerous in daily practice and may lead to great disappointment and extra costs. The causes of failure of restorations involving endodontic posts have been investigated in a number of clinical studies [4-10]. These studies suggest that failures are due mainly to the mechanical properties of the post and core.

A complicating factor is root fracture; here is consensus that the root is put at risk when a post is too short or too long [1,9,11-13]. Increasing the thickness of the post adds to its strength, but as this is at the expense of the supporting tooth structure, the effect may well be a reduction in the overall strength of the assembly [1,9]. Furthermore, findings indicate that the amount of axial dentin surrounded by the crown is more important than the length of the post. A minimum of 1.5 mm ferrule is essential [14-18]. Another complicating factor is the rigidity of the post. Some researchers support the view that a post of high rigidity leads to a more even distribution of the stress [1], while others claim that a less rigid endodontic post is preferable [9,11,12,19].

Now that several adhesive systems have become available, the main question is not only which combination of post and core is the most predictable and durable, but also in which cases there is no need for a post at all. There are indeed good reasons to avoid the use of a post. One of the main disadvantages of a post is the necessity to re-enter the root canal. Preparation for the post creates a risk of root perforation. In addition a nearby perforation may cause a small root fracture, later resulting in a failure of the restoration. This risk is especially high with premolars, which may have unexpected constrictions at the mesial and distal surfaces of the root [20]. Tooth anatomy is variable and each case may require an individual approach. It is the clinician who must decide on the restoration design and select the right materials.

The mechanical properties of post and core restorations have been studied extensively. However, the clinical relevance of the data in these studies is questionable, because they tested only the resistance to extensive loading of the post and core. In view of the clinical performance
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of this type of restoration, it is more realistic to load the entire assembly of post, core and crown, rather than simply the core [21].

It was the aim of this study to compare the resistance to fracture of various core materials in combination with a full crown restoration. A standardized test set-up was developed to exclude the variances resulting from differences in size and shape of the tooth with the anatomic crown removed, the preparation of the core, and the crown itself.

2.3 Materials and methods

Preparation of the tooth

In this study 56 extracted human premolars were used to prepare seven groups (Groups1-7) of eight teeth each (n = 8). With a low-speed, water-cooled diamond separation disk (Buehler Ltd) the coronal section of each premolar was removed 4 mm above the proximal cemento-enamel-junction (CEJ). The tooth with the crown removed, here after referred to as the sectioned tooth, was then endodontically treated by cleaning the root canals with Gates Glidden drills (Dentsply/Maillefer) nos. 2, 4, 5 and rinsing with 2% NaOCl. After closing the apical foramen with a resin-based composite, the root of the premolar was embedded in acrylic resin inside a standard copper tube, leaving 6 mm of the root exterior to the acrylic. During the setting of the resin, the specimens were kept humid to avoid dehydration of the dental tissue.

To achieve standardization in the preparation of the specimens, the “key-duplication” method was used for six groups. With the high-speed, water-cooled diamond burs of the Celay machine (Microna Technology Inc) (Figure 2.1) it is possible to cut the tooth in conformity with a master die attaining an accuracy of 80 μm. Two brass master dies were machined for each step in the preparation.

After the copper tube was marked on the buccal and lingual (palatal) side of the tooth, in order to control the load direction, each specimen was aligned in the Celay machine with the first master die and fixed on a brass disk with cyanoacrylate (Figure 2.1). This first master was used to complete the preparation of the flat occlusal surface of a sectioned premolar, and to enlarge the entry of the root canal of the tooth. The dimensions of the first master die and the sectioned tooth are shown in Figure 2.1. In the seventh group the teeth were prepared by hand with high-speed, water-cooled diamond burs, as close as possible to the dimensions of the first master.
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Fig 2.1 The Celay machine, a copy-milling device, using the key-duplication method to copy a master (upper left). The alignment of the first master and the sectioned premolar in the Celay machine (upper right). The position of the sectioned tooth in the cupper tube, leaving 6 mm of the root exterior to the acrylic resin and the dimension of the first master in mm (lower drawing).

Core Restoration

Immediately after the first preparation step, the tooth was rebuilt. A standard matrix was placed around the premolar, and filled with an excess of core material. During setting the core material was kept under occlusal finger pressure. After setting, the premolar with core was prepared again, but now in conformity with the second master die (Figure 2.2). This standard crown preparation was, in accordance with the ferrule rule [17], ending in 2 mm sound dentin (Figure 2.2). The total height of the core plus the ferrule was 7mm and the total taper of the opposing surfaces of the preparation was 20 degrees. The finishing line of this full crown preparation was a shoulder of 0.5 mm. The dimensions of the second master die and premolar with core are shown in Figure 2.2.
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Fig 2.2 The second master has the shape of a standard-crown preparation (upper left): The premolar with core build-up material is cut in conformity with the second master (upper right): The final crown preparation on the premolar with core build-up and the dimension of the second master in mm (lower drawing).

In this way six groups were prepared. In the two groups where a post was used, the canal space was prepared with calibrated drills, which are part of the post systems, to a depth of 6 mm from the occlusal flat prepared surface. This method allowed investigating different core materials under equal dimensional circumstances. For the seventh group the crown preparation was made by free hand, trying to duplicate as close as possible the dimensions of the second master die.

In group 1 (Ti-Core without post) the dental tissue of the shoulder and pulp chamber was etched for 30 seconds with 32% phosphoric acid (Bisco), thoroughly rinsed with water and dried but not dehydrated. One coat of One-Step Bond (Bisco) was applied, air dried for 12 seconds and light-cured for 10 seconds with the Translux CL (Kulzer). A second layer was applied in the same way. The chemical-cured resin composite Ti-Core (EDS) was mixed and applied to the
tooth with a Centric syringe (Hawe Neos Dental). After 10 minutes, the standard crown preparation was started.

In group 2 (Photo Core without post) the dental tissue of the shoulder and pulp chamber was etched for 30 seconds with 32% phosphoric acid, thoroughly rinsed with water, and dried. Clearfil SA primer (Kuraray) was applied and the preparation was dried again but not dehydrated. Then one layer of Clearfil Photo Bond (Kuraray) was applied; after the excess was blown away, it was light-cured for 20 seconds. With a Centric syringe light-cured resin composite Clearfil Photo Core (Kuraray) was applied to the tooth and light cured for 60 seconds. Immediately afterwards the preparation was started.

In group 3 (Ketac-Molar without post) the dental tissue of the shoulder and pulp chamber was conditioned with Ketac-conditioner (3M-ESPE) for 10 seconds, rinsed with water, and dried but not dehydrated. The chemical-cured glass-ionomer core build-up material Ketac-Molar (3M-ESPE) was mixed in a capsule and applied to the tooth with a Centric syringe. After 7 days the standard crown preparation was started.

In group 4 (Cast post and core) the depth of the post was 6 mm, measured from the shoulder. The preparation of the root canal was performed with a calibrated drill (code yellow, diameter 1.3 mm), part of the Tenax endodontic post system (Coltène Whaledent). By means of the direct method the sectioned premolar was built up with a corresponding Tenax burnout post (code yellow, TE-EP 13) (Coltène Whaledent) and Duralay resin (Dental Mfg.). The burnout post displayed an adequate fit in the apical part of the root canal. In the more spacious medial and coronal part of the root canal, where the diameter of the calibrated drill was not always sufficient, the post was adjusted with Duralay. A standard matrix was placed around the premolar and filled with Duralay to form a core build-up pattern. After 10 minutes the preparation of the standard crown was started. When completed, the post and core pattern was removed and used to cast a permanent post and core in a non-precious Phantom metal (Degussa). Then it was cemented into the root canal with the glass-ionomer luting agent Ketac-Cem (3M-ESPE) by using a Lentulo paste carrier (Dentsply/Maillefer).

In group 5 (Photo Core with a silica-fiber post) the depth of the post was 6 mm. The preparation of the root canal was performed with a calibrated drill (code white, diameter 1.0 mm), part of the Snowpost system (Carbotech), and corresponded to the silica-fiber post. The dentin of the root canal and the shoulder was etched with 32% phosphoric acid, rinsed with water, and dried with paper points, but not dehydrated. Then the dentin and the post were conditioned for 60 seconds with the mixture of Panavia Primer A and B (Kuraray). The excess primer was blown away; in the root canal this was done using absorbent paper points.
The Lentulo Paste Carrier was not used for Panavia 21 as this method involved the risk of an accelerated setting of the cement, due to the contact with the primer and the anaerobic conditions in the apical part of the root canal. Premature setting of the cement would make it difficult to get the post in place. Therefore the silica-fiber post was coated with an excess of Panavia 21 before it was placed in the root canal; the coronal part of the post and the dentin shoulder were also covered with a thin layer of Panavia 21. The post was kept 3 minutes in place and then Clearfill Photo Core was applied to the tooth and light-cured for 60 seconds. Immediately afterwards, the standard crown preparation was started.

In group 6 (No core and no post) the sectioned tooth was not rebuilt with core material, but only prepared in conformity with the second master die. This affected only the 2 mm axial dentin, in which a shoulder was prepared.

In group 7 (Non-standardized Photo Core without post) the dental tissue of the shoulder and pulp chamber was etched for 30 seconds with 32% phosphoric acid, thoroughly rinsed with water and dried. SA primer was applied and the preparation was dried again, but not dehydrated. Then one layer of Photo Bond was applied, the excess was blown away, and it was light-cured for 20 seconds. Using a Centric syringe, Clearfill Photo Core was applied to the tooth and light-cured for 60 seconds. Immediately afterwards the crown preparation was started.

Manufacturing of the standard crown

The device for the manufacture of standard crowns was fabricated in brass (Figure 2.3). The second master die (A) was fixated at the bottom of the cylinder (B). Using the stamp (C), heated (55 °C) Prepon modeling wax (Bayer) was pressed onto the master. The excess was drained away trough two small holes (D). The load required to move the stamp down was delivered by a hydraulic prosthesis press (Fino). After cooling, the wax crown was removed from the cylinder by removing a ring (E). It was then cast in metal (Degussa). The result was a circular crown (F) with a standard dimension. The height was 10 mm, external diameter 3.5 mm and the occlusal surface was flat. Thanks to the accuracy of the Celay machine, the crown displayed a good fit on the standard prepared core build-up (G).

Figure 2.3 shows this standard crown with the three different types of core in the groups investigated. The crown was then cemented with Ketac-Cem (3M-ESPE). The specimens (H) were stored for 24 hours under humid conditions at a temperature of 37 °C before they were exposed to the loading procedure.
Fig 2.3 The procedure for the manufacture of standard crowns (upper left). The universal testing machine that loaded the specimens until fracture in a buccal-lingual direction at 45° (upper right). In schedule the three different kinds of core build-up in the groups investigated. Two crowns are supported by a core build-up, without and with post, and the third is not supported by core material (lower drawing).

**Strength determination**

The specimens were loaded until fracture in a buccal-lingual direction at 45° in a universal testing machine (Figure 2.3) (Instron). The crosshead speed was 0.5 mm/min. The stress-strain curves during loading were recorded. Eight specimens from each group were investigated, and ANOVA statistics were used to evaluate the results.

2.4 Results

An analysis of variance was performed with the maximum load as the dependent variable. The type of material was regarded as a between-subjects factor. The mean values are presented in Table 2.1.
Fracture resistance of different core build-up designs

Table 2.1 Mean fracture load of restored premolars, loaded in buccal-lingual direction at 45° in a universal testing machine

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Mean (N)</th>
<th>Std. Deviation (N)</th>
<th>Std. Error (N)</th>
<th>Lower Bound (N)</th>
<th>Upper Bound (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ti-Core</td>
<td>8</td>
<td>736</td>
<td>141</td>
<td>50</td>
<td>617</td>
<td>854</td>
</tr>
<tr>
<td>Photo Core</td>
<td>8</td>
<td>743</td>
<td>166</td>
<td>59</td>
<td>604</td>
<td>882</td>
</tr>
<tr>
<td>Ketac-Molar</td>
<td>8</td>
<td>703</td>
<td>129</td>
<td>45</td>
<td>596</td>
<td>811</td>
</tr>
<tr>
<td>Cast post and core</td>
<td>8</td>
<td>835</td>
<td>121</td>
<td>43</td>
<td>734</td>
<td>936</td>
</tr>
<tr>
<td>Photo Core and SF post</td>
<td>8</td>
<td>590</td>
<td>190</td>
<td>67</td>
<td>431</td>
<td>748</td>
</tr>
<tr>
<td>No core</td>
<td>8</td>
<td>714</td>
<td>73</td>
<td>26</td>
<td>653</td>
<td>774</td>
</tr>
<tr>
<td>Free hand made Photo Core</td>
<td>8</td>
<td>542</td>
<td>225</td>
<td>80</td>
<td>353</td>
<td>730</td>
</tr>
</tbody>
</table>

The material main effect proved to be significant (P = 0.01). This effect is illustrated in Figure 2.4; for No core, Ti-Core, Photo Core and Ketac-Molar, the maximum load was on roughly the same level, while for Photo Core + silica-fiber post and HM Photo Core, the average reading of the load was somewhat lower, and for cast core somewhat higher. Bonferroni pairwise comparisons were then calculated. Only for the HM Photo Core and the cast post and core the fracture load was significantly different (P = 0.01). In addition, this hand-made group displayed a larger standard deviation than the standardized groups.

Fig 2.4 The mean fracture load (N) and standard deviations of the crowns with different kinds of cores.
2.5 Discussion

Although the preparation procedures of the sectioned premolars were standardized, the resulting preparations were not always an exact copy of the brass master die, due to the fact that the premolars were oval. Thus in many cases, not enough dental tissue was available on the mesial and distal surfaces of the sectioned premolar to copy the master die completely. Therefore the amount of dentin substrate, available to bond to core material, showed some variation on the mesial and distal surfaces, and the cemented crowns had an overhang in those areas. In daily practice this occurs fairly frequently as a result of an inadequate impression. However, on the buccal and lingual (palatal) surfaces, the direction in which the specimens were loaded, the copy was accurate. The use of an oval master die would cause difficulties in the alignment of the specimen and the master in the Celay machine, but a recent development will probably enable us to solve this problem in the near future. Using this method the time consuming impressions and expensive manufacture of individual crowns can be avoided, since the standard crown shows a good fit on all specimens. Moreover, this method excludes undesirable variances in the size and shape of the sectioned tooth, the core, and the crown itself.

The results of the loading tests show that, as expected, the highest mean value of the fracture loads was found for crowns supported by a cast core (Group 4). However, there was no statistical difference between group 4 and the other standardized groups. Furthermore, the use of the silica-fiber post to reinforce a resin composite core build-up did not improve the resistance to fracture; indeed, it was striking how quickly these silica-fiber posts broke. Finally, it is noteworthy that there was no statistical difference between the mean fracture load for crowns without cores and crowns with cores.

Since most patients have a maximum bite force in the premolar region close to 580 N [22], the findings in this test set-up suggest that if a crown surrounds a bulk of 2 mm axial sound dentin, no core material is required. However, clinically another failure mechanism may be decisive. Nevertheless, it appears that for this kind of restoration the 2 mm axial dentin is playing an important role in the resistance to fracture. This is in accordance with other studies [17,18], in which it was concluded that the resistance to fracture of crowned teeth is clearly related to the ferrule length.

The fracture load of specimens in the seventh group (HM Photo Core) showed a wider variance. The standardized test set-up enabled us to reduce the standard deviation and to increase the number of specimens. Further investigation into the influence of the amount of axial dentin (ferrule) and post support is needed. This can be facilitated by the standardized test setup, as it is
possible to vary the quantity of remaining dental tissue (with the ferrule width as the variable) without changing either the dimensions or the position of the crown preparation.

It has to be realized that, so far, this in vitro study regarded only a part of all aspects involved with the clinical reliability of the performance of these crown and core combinations. For clinical studies showed that many core restorations fail after years of service [4-6,8-10,23] and therefore the influence of fatiguing the specimens and the effect of small loads at a 90° angle must be investigated. Furthermore, the absence of an artificial periodontal ligament may have influenced the stress distribution in the root, causing root fracture in some of the specimens.

A dentist who plans to restore an endodontically treated premolar with a porcelain fused to metal crown, should be aware of the fact that the esthetic tendency to strive for a porcelain shoulder at the lingual (palatal) side is in conflict with the results of this study, since the preparations for this type of crown involve a greater loss of axial dentin. Therefore, when a full crown preparation is indicated for an endodontically treated premolar, a conservative approach to the axial dentin is advisable. The consequences of this approach - less space for porcelain in the cervical area - is a finish line in metal. However, at the lingual (palatal) side of a premolar, and at the buccal side where the cervical line of the tooth is not manifest, this does not interfere with the esthetics and will ensure a more durable restoration.

2.6 Conclusion

Within the limitations of the test set-up used in this study, it can be concluded that:

- When a full crown preparation is indicated for an endodontically treated premolar, a conservative approach to the axial dentin is advisable.
- A core build-up without a post and made with adhesive resin composite can be a viable alternative for the conventional cast core when a minimum of 2 mm ferrule on natural tooth structure is attainable.

2.7 References

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