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CHAPTER 7

Summary and Clinical Discussion

7.1 Summary

Due to its location in the dental arch the premolar in the majority of the people is well visible during speaking and laughing. Therefore high esthetic requirements are demanded for restorations in these teeth and in particular today. When endodontic treatment of a premolar is necessary due to progressive deterioration by caries, often a considerable amount of coronal tooth structure is lost. In certain cases only palatal and buccal tooth structure has remained being so severely undermined or weakened, that an indirect restoration is required to resist occlusal bite and chewing forces. This could be realized with partial onlay restorations made of gold or porcelain. Unfortunately, in these cases dentists often prefer to restore the tooth with a full crown. A gold onlay is avoided for esthetic reasons and a porcelain onlay because of the risk of fracture. Another aspect is that clinicians experience its preparation or luting procedures as time consuming and difficult. Another reason to restore the tooth with a full crown is a discoloration of the tooth, due to previous amalgam and endodontic restorations.

However, the conventional gold-porcelain and all-ceramic crowns strengthened with zirconium-oxide cores, have the disadvantage that a considerable amount of what is left of the palatal and buccal tooth structure has to be cut away to allow the technician sufficient space to fire the porcelain in multiple layers onto the metal or the core. Only then, an all-ceramic crown will meet the requirements of esthetics and original shape. However with this restorative procedure there remains ample mechanical retention for the build-up restoration, which has to be prepared to provide the necessary support for the crown. Therefore when using this approach one chooses for placing posts in one or more root canals to offer the build-up restoration extra stability and retention in the remaining tooth structure.

Daily practice shows that the restorative method and the application of post and core build-up restorations, as described above are not without risks. In particular with premolars these kinds of restorations seem to show retention failure and to lead to vertical root fractures more often than other teeth restored in the same way. It is assumed that besides the unfavorable small mesial-

distal width of the root, also an unfavorable distribution of stresses in the root dentin by the posts is responsible for such root fractures. A study of the anatomy and literature about the premolar indeed shows that the use of posts should better be avoided for this tooth. For cases where too little tooth structure remains and the use of a post is essential for adequate retention of the build-up, a relatively short post should be chosen. Seating the post in the root canal with an adhesive cement can compensate for the lower retention of a short post as compared with a long post. However, short metal posts have the problem that they can cause relative unfavorable stress distributions in the root dentin by functional loads. This may be overcome with the new generation of posts made of longitudinal oriented carbon or glass fibers embedded in a resin, as they have an elastic module (stiffness), which is more close to the elastic module of the tooth structure compared with metal posts.

For further improvement of the quality of the build-up restoration it is essential that the build-up material is adhesively bonded to the dentin and that the clinician is aware that in bonding procedures shrinkage stresses will occur during setting of the build-up materials. The large variety of bonding systems available will possess great differences in chemical compositions and can easily lead to incompatibility with chemical or light-cured composites, if a wrong combination is accidentally chosen.

This thesis describes a number of studies that provide data about the fracture resistance of different kinds of post and core build-up restorations with a relatively short post length of 6 mm and knowledge about their behavior in fatigue experiments. Apart from traditional cast post and core systems, also titanium and the new carbon fiber and glass fiber posts were included in the experiments. In addition a study was performed on shrinkage stresses that occur during setting of chemical-cured and light-cured build-up composites and on the compatibility of different bonding systems with these build-up composites.

Chapter 1, being the introduction of this thesis, describes how post and core build-up restorations originated and which build-up materials, posts and procedures have been used through time. Furthermore it describes what the important role is of the restorative embracement of the tooth structure (ferrule) and the preservation of tooth structure, which stresses are distributed in the root when posts are used, what the advantages and disadvantages are of the various cements that are used to place posts into the root canal, why the premolar is less suitable to be used with posts, and finally which methods are being used up till today to evaluate build-up restorations for endodontically treated teeth.

Chapter 2 describes how post and core build-up restorations with a crown were prepared on premolars in a standardized manner in order to compare the strength of different core build-up

restorations. Premolars were embedded in a resin in copper tubes and decapitated in a standard manner in the Celay machine. Subsequently the decapitated teeth were restored with a post and core restoration and again trimmed in the Celay machine to produce a preparation for a standard crown, which was finally cemented on top of it. In this way different types of build-ups were prepared in premolars and evaluated on strength. Besides the importance of equal dimensions for all build-ups, another important aspect was that the metal crown, which was cemented on the build-up, embraced 2 mm of tooth structure below the build-up. Its effect on crown retention is called the ferrule effect. All specimens in the groups studied, each with eight test specimens ($n = 8$), were loaded until fracture in buccal-palatal direction under an angle of 45° . In two groups the specimens had build-ups with posts in the root canal, the first one with a cast post and core of a non-precious metal and the second one with a light-cured build-up resin-composite and a silica fiber post. For three other groups the specimens had build-ups without posts, where the build-up of the first group was a chemical-cured composite, that of the second group a light-cured composite and that of the third group a glass-ionomer cement. There were two control groups, one to learn about the contribution of the ferrule and one to find out whether the standard deviations in the standardized test set-up were smaller than in a non-standardized set-up where specimens were obtained by free-hand preparation. The first control group comprised specimens, which were *not* built up with a build-up material, but where the retention of the crown was determined solely by the cement layer on 2 mm ferrule. In the second control group each tooth was decapitated with an airrotor to the same level and built up with a light-cured composite and prepared with the airrotor for a crown preparation of comparable dimensions as used in the standard test set-up, and including a ferrule of 2 mm. After making an impression of these preparations, crowns were made in the dental lab for each preparation individually (with approximately the same dimensions as those of the standardized groups) and finally cemented on the build-up.

The results showed the highest average fracture resistance for crowns, which were supported by a cast post and core build-up. For this type of build-up all specimens underwent root fracture at the maximum load. The average value of this group only showed a significant difference with the group where the support for the crown consisted of a silica fiber post and composite build-up. A remarkable finding was that the first control group, which had no build-up at all, did not differ significantly from the other groups. Apparently the ferrule effect from the embracement of tooth structure by the crown plays a very important role in determining the maximum fracture strength. In particular in this test set-up where the specimens were loaded under an angle of 45° and only a narrow shoulder of 0.5 mm was prepared in the axial dentin, the tooth structure at the margin of

the crown appeared to contribute for a great deal to the fracture resistance. Furthermore, the results showed that the standard deviation of the non-standardized group was higher than those in the standardized groups.

It was concluded that for the determination of the fracture resistance of build-ups with crowns, the ferrule plays a determining role, if a test set-up is used when the load is applied under an angle of 45°. To obtain a better picture of the contribution of the post and core build-up of the ultimate fracture strength, a test set-up with a load direction more perpendicular to the axis of the root seems preferable. For the general practice this study indicates that a ferrule is recommended, but the dentist should keep in mind that tooth structure has to be preserved as much as possible.

In Chapter 3 two groups of premolars with eight test specimens ($n = 8$) were prepared with conventional cast post and cores with a post length of 6 mm and a core height of 5 mm. In the first group zinc phosphate cement was used to cement the cast post and cores and in the second group a chemical-cured resin-composite cement was used. Half of the specimens of each group was subjected to fatigue loading, while the other half served as a control. The specimens for the fatigue experiments were embedded in copper tubes with an acrylic resin and placed in PVC blocks in the fatigue machine. Prior to embedding the teeth in the acrylic resin, the roots were first coated with a thin silicon layer to imitate the periodontal ligament. The test specimens were loaded in the fatigue machine for one million cycles with a load of 40 N at a frequency of 1 Hz. The load was applied in buccal-lingual direction on the occlusal-axial corner of the core, at an angle of 85° with the axis of the post. A crown with a ferrule was deliberately omitted in the test specimens as to subject the build-up to fatigue under the most unfavorable conditions. Failure as a result of fatigue is defined as the breaking or fracturing of a material caused by cyclic or repeated applied loads below the yield limit, usually noticed initially as minute cracks followed by tearing and rupture until deterioration into small fragments.

To evaluate the quality of the cement layer between post and root dentin of the fatigued specimens and the control specimens (non-fatigued), three parallel transverse sections of 1.5 mm thickness at the apical, medial and coronal level were cut from the part of the roots, which contained the 6 mm post. Impressions were made of each of the sections at the coronal surface and poured in epoxy resin to produce replicas. These were examined in the scanning electron microscope (SEM) for scoring irregularities like cracks and air-bubbles in the cement layer and insufficient adaptation of the cement to the post or dentin. The original sections were used to evaluate the retention of the post segment in the root canal with the Push-out test. In this set-up each cross-section was positioned with the coronal plane downwards and the central post

segment centered over a hole in a steel support and was pressed downwards in a universal testing machine to record the push out load.

The results showed that fatigue loading did not cause separation of the build-ups from the roots in any of the specimens. There were also no significant differences between the fatigued and non-fatigued specimens in SEM evaluation scores or Push out strengths. Differences were only found between the types of cement, of which the resin-composite was significantly better than the zinc phosphate cement with regard to both the SEM evaluation scores and the Push out strength.

In **Chapter 4** the same test set-up was used as in chapter 3 and also the specimen dimensions were the same. In this study all posts were cemented with the same cement, which was a chemical-cured cement, but various post and core combinations were used. In the first group conventional cast post and cores were used, while in three other groups a prefabricated post was combined with a light-cured composite build-up material, which was bonded to the dentin with an adhesive. The prefabricated posts were either titanium posts, or resin-reinforced glass fiber posts, or resin-reinforced carbon fiber posts. Under similar conditions as those in chapter 3, half of the specimens was exposed to fatigue loading and the other half was used as a control. The quality of the cement layer between the posts and root dentin was evaluated by SEM and the Push out test, similarly as in Chapter 3.

Also in this part of the study none of the specimens fractured during fatigue loading and there were no significant differences in Push out strengths between fatigued and non-fatigued specimens, but SEM analysis of the cement layer did show significant differences. With regard to the post and core combinations, SEM showed that the cast post and core and the glass fiber and carbon fiber posts with composite core performed equally well, but that the titanium post with composite core performed significantly worse. Another result from the SEM evaluation was that the quality of the cement layer significantly improved from apical to coronal.

In **Chapter 5**, again the same test set-up and quality evaluation methods were used to study the influence of fatigue loading of post and core build-ups. In this study all specimens consisted of a carbon fiber post and a build-up of a light-cured composite, which was adhesively bonded to the dentin, but the variable was the type of luting cement to seat the posts in the root canals. In the first and the second group a chemical-cured and a dual-cured resin composite cement was used and in the third group a resin-modified glass-ionomer cement.

The SEM analysis and Push out results showed that fatiguing was just not significantly different from the non-fatigued control. Significant differences were found between the cement types and the location of the post section (apical, medial, and coronal). With regard to cement

type, both SEM scores and Push out strengths improved from resin-modified glass-ionomer cement to dual-cured composite cement, followed by chemical-cured composite cement. The quality of the cement layer between post and radicular dentin improved from apical to coronal.

In Chapter 6 a study is described that dealt with compatibility of core build-up composites and modern bonding systems, investigated with polymerization shrinkage stress measurements and dentin bond strength determinations. It was shown that the type of bonding system combined with chemical-cured composites is of influence on bond strength. This may be due to the acidic monomers that are included in the compositions of bonding systems to enhance etching capacity and hydrophilicity. The presence of acids at the contact surface between adhesive and composite can be a disturbing factor, as H^+ - ions can react with the tertiary amines, which are essential for the polymerization reaction to occur. Normally the composite and the oxygen inhibition layer on top of the adhesive will intermix and firmly unite after polymerization. As chemical-cured composites polymerize slowly, polymerization at the composite-adhesive contact surface will be adversely affected, if the acidity (pH) of the oxygen inhibition layer is too low. One of the tested bonding systems, which contained a salt of a weak acid (sodium benzene sulphinate) did not show this problem, probably because the free H^+ - ions bind to the benzene sulphinic anion more quickly than to the tertiary amine. Light-cured composites were not affected by the acidity of bonding systems, which is explained by the faster curing rate directly after application allowing little time for adverse reactions to occur.

Further it was demonstrated that shrinkage stresses of chemical-cured composites developed much slower and that in a few cases the ultimate stresses were lower than in light-cured composites. This is due to the slower setting rate of chemical-cured composites compared to light-cured composites, which cure abruptly and almost completely during light irradiation. It has been demonstrated that both build-up composites, chemical and light-cured, bonded well to dentin with most of the investigated adhesives and were not disrupted by the polymerization shrinkage stresses.

7.2 Clinical discussion

There is still a large demand on root canal posts, which is confirmed by the dental enterprises that frequently introduce new and "better" post systems. In the Netherlands posts are used in approximately 30% of the core build-up restorations on endodontically treated teeth [1]. Indication criteria used for this kind of restorations are based on literature knowledge, personal experiences or conviction. In these cases many dentists assume that the post provides an

indispensable contribution to the strength and durability of the core build-up restoration. Of course, there are cases where so little tooth tissue is left that a root canal post is necessary for additional retention of the core build-up restoration, but there are also other considerations for placing a post. The mechanical requirements of a core build-up restoration depend, amongst others, also on the position in the jaw. In an anterior region with unfavorable occlusion or articulation, loads may include relatively large horizontal stress components. In the molar region the loads are less perpendicular to the restoration, but generally have higher values. Additionally, for a single crown other properties are required than for an abutment for a large bridge construction or frame prosthesis. Finally also patient-dependent factors like bruxism, erosion, oral hygiene etc. can be decisive. Within this spectrum of variables the dentist has to determine for each case separately, which approach is the best.

This study showed that for a core build-up restoration, without root canal post, adequate retention to the tooth could be obtained by using contemporary adhesive techniques. In general practice, in the majority of the cases enough tissue will remain to use this technique. Moreover, the irregular shape of the remaining excavated dentin will also provide mechanical retention. Therefore, it is of importance to save as much tooth structure as possible. As a consequence, for a full crown preparation the dentist has to find the balance between sufficient ferrule and minimum loss of healthy tooth structure. This can be of importance because in the absence of a rigid post cervical stress levels can be higher. The lower the elastic modulus of the core build-up material, the higher the stress levels [2]. The consequence of this approach is that, in preventing an over-contour of the restoration, the crown margins must be thin and of metal, which will affect the aesthetics of the restoration. It is the duty of the dentist to inform the patient about the choice, which has to be made between preservation of the tooth structure and aesthetics. In the test set-up of the first study a ferrule with minimal removal of tooth structure is achieved by preparing a shoulder of 0.5 mm only.

In the study with regard to the quality of the cement layer between post and intra-radicular dentin it was illustrated that the root canal is a complicated area, in which it is difficult to create a cement layer of constant quality. For this reason one should avoid that retention of a core build-up restoration mainly depends on the root canal post, and create adhesive retention on the remaining tooth tissue outside the root canal as much as possible. Therefore, preservation of supra-gingival tooth structure is required. It should be clear that a complete crown concept conflicts with this principle and for that reason the dentist should prefer restorations where buccal and palatal (lingual) tooth structure is preserved. Therefore adhesively placed

restorations that replace the tooth cusps, indirectly made of metal or porcelain, or directly made of composite, are first choice.

In the last study it has been shown that a low pH value of the adhesive bonding can reduce the adhesive bond strength of self-cured resin composite to dentin. When failure of the core build-up restoration occurs in these cases, the assumption that a root canal post has been necessary for adequate retention of the core build-up restoration may not be justified.

A disturbance of the polymerization reaction of build-up resin composites may occur in a chemical comparable manner with self or dual-cured resin composite cements when no separate adhesive bonding between cement and dentin is used, but where the cement is bonded directly to the dentin. Many of these cements make use of self-etching primers to condition the dentin. These self-etching primers, which have a low pH, are not removed and remain on the dentin. They come in direct contact with the resin composite cement and can disturb its polymerization as described in Chapter 6. To overcome this problem some manufacturers add a salt of a weak acid to the primer, as is also done for bonding systems with a low pH. Another problem is that resin composite cements often show an accelerated setting under oxygen free conditions like those encountered in the apical part of the root canal and have to be manipulated very fast. Primers that contain initiators can even intensify this accelerating effect on the setting of cement and shorten the working time even more. Therefore, for a good quality of the cement layer between post and dentin, slow setting cements should be preferred as more time is available to apply the cement in an adequate way into the root canal before the post is seated.

The study has also shown that a self-cured build-up resin composite needs at least 10 minutes before a reasonable bond strength is obtained to allow trimming and finishing. However the crown preparation is often already started earlier, because the dentist judges from the hardness of the material, that the resin composite is already fully cured. The clinical consequences of early preparation are not clear. An advantage of the light-cured core build-up composite is that most of it will be polymerized after light-radiation and can be prepared immediately. The shrinkage stresses are somewhat higher, but in an area with an unfavorable C-factor (pulp chamber and entry of the root canal) this can be compensated by applying the composite in layers. For the coronal portion this aspect is of minor importance, because the shrinkage of the resin composite is largely unhindered.

7.3 Future studies

Literature [3-5] and the results of this study have shown that, after the root canal has been prepared for an endodontic post, remnants of root canal filling material (root canal sealer and gutta-percha) may remain. By etching the canal with 32% phosphoric acid, followed by thoroughly rinsing with water, the largest part of these remnants can be removed and after an adhesive bonding is applied a thin flexible layer between cement and dentin can be created. This procedure is indeed more complicated than for resin composite cements where only a primer is used, but the advantage may be a better penetration of the adhesive bonding into the dentin tubules when compared to more viscous resin composite cement [6,7]. Moreover the flexible adhesive bonding layer may relieve the high shrinkage stresses (the C-factor is unfavorable) in cement to some extent. The possible advantages of this approach, including the application of cements in the root canal by using needle tubes, have to be examined further. Beside the bond strength also leakage have to be investigated. The main objective should be to develop a system, where the adhesive components adequately bond to dentin and post, polymerisation shrinkage stress development can be minimized, and the endodontic seal can be guaranteed. A test set-up for this is already developed.

Another aspect that deserves attention is the fracture strength of endodontically treated premolars that are restored with partial direct or indirect adhesively bonded restorations. This study should also include the stress distribution in the remaining tooth tissue. Developments in CAD-CAM technology [8] and improved handling of resin composite materials have opened ways where the preservation of tooth tissue can have priority. From this perspective also progress can be made when predictable results can be realized with direct pulp capping techniques [9-13], this in stead of complete root canal procedures for which much more tooth structure has to be removed.

Beside *in vitro* investigations also *in vivo* studies can provide important data about the success rate of different core build-up systems. The problem however, is that these retrospective investigations study core build-up systems on teeth for which the loss of tooth structure is varying. This last aspect may also influence the choice of the type of build-up system. Anyway, in future studies in this context, preservation of tooth structure, which is actually irreplaceable, should be the target. This point of view appears to be more and more supported by the dental profession [14]. It is clear that for this approach adhesive dentistry is an indispensable link.

7.4 References

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