Basic and clinical aspects of selection and application of fiber posts

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CONTENTS

Chapter 1  General Introduction .................................................................3
1.1 Differences between healthy and root canal treated teeth ..........................4
   1.1.1 Changes in the physical and chemical properties of the tissue ............5
   1.1.2 Changes in the morphology and in the biomechanical behavior of teeth under stress .................................................................6
   1.1.3 Possible elevation of pain threshold and loss of pressoreceptors ......7
1.2 Relation between fracture resistance of the endodontically-treated teeth and presence of posts ..............................................................8

Chapter 2 The use of fiber posts in dentistry ...........................................16
2.1 The use of fiber posts ........................................................................16
2.2 Fabrication process and structure of fiber posts ......................................16
2.3 Structure and mechanical properties of fibre posts ..............................18
2.4 Metal posts versus fiber posts ..............................................................19
2.5 Role of the final restoration design (ferrule effect) ..................................20

Chapter 3 Preparation of root canal dentin to bonding ..........................26
3.1 Evaluation of Glyde File Prep in combination with sodium hypochlorite as root canal irrigant: a scanning electron microscopic study .................28

Chapter 4 Criteria for selecting fiber posts .............................................41
4.1 Fatigue resistance and structural characteristics of fiber posts: three-point bending test and SEM evaluation .............................................41

Chapter 5 Adjusting the length of a post ...............................................60
5.1 Scanning electron microscopic investigation of the surface of fibre posts after cutting .................................................................60

Chapter 6 Selection of clinical luting procedures .....................................70
6.1 A one step procedure for luting glass fibre posts: an SEM evaluation .......71

Chapter 7 Anatomic Post: an innovative approach ..................................85
7.1 SEM evaluation of the cement layer thickness after the luting procedures of two different posts ..........................................................85
7.2 Use of Anatomic Post’n Core for reconstructing an endodontically treated tooth: a case report .............................................................94
Chapter 8  Clinical aspects and future role of fiber posts in dentistry ……113
8.1. Clinical evaluation of the use of fiber posts and direct resin restorations for
derodontically-treated teeth ................................................................. 113
Chapter 9  Summary and conclusions ............................................129
Riassunto e conclusioni ..................................................................135
Résumé et conclusions ..................................................................142
Schlußfolgerung ..........................................................................149
Resumen y conclusiones ..............................................................155
Sumário e conclusões ...................................................................162
Complete list of references ..........................................................169
Acknowledgements .....................................................................183
CURRICULUM VITAE .................................................................185
Chapter 1  General introduction

The restoration of the endodontically-treated teeth has always been a debated topic. A tooth requires endodontic treatment as a result of caries, repeated restorative procedures, or trauma. Many changes occur to a tooth after root canal treatment, including the physical and chemical properties of dentin, its elasticity, resistance to fatigue, changes in the morphology and biomechanical behaviour. As early as 1746, Fauchard (Fauchard, 1746) proposed the insertion of wooden dowels (the first real “fiber post”) in canals of teeth to give support to crown retention. Since then, many different materials have been proposed for “reinforcement” and retention of the restorative core.

This thesis contains a study on several different basic and clinical aspects related to the selection and use of fiber posts. Starting from the assessment of the differences between healthy and root canal treated teeth, the next step was to analyse the relationship between the presence of a post and root fracture. Fiber posts were the first true alternative to metal posts, and they jeopardized in the dental market in the last 10 years; for this reason an overview regarding the properties, advantages and disadvantages of fiber reinforced materials is presented.

A clean and neat root canal is one of the goals pursued during endodontic treatment. The first objective of this thesis was to evaluate different irrigating regimes to achieve a clean root canal before guttapercha condensation procedures and eventually the insertion of the post.

As actually many fiber posts are available on the market, it is important for the clinician to know the properties of each fiber post available on the market, and to consequently select the more appropriate. The second was indeed to conduct a study to assess the fatigue resistance of different types of fiber posts, and to verify the existence of a correlation between the fatigue resistance exhibited by the different types of posts and their structural characteristics. These are also very important when calibrating a post before or after the luting procedures. Another goal of this thesis was in fact to evaluate if and how three cutting methods can affect integrity of fibre posts, and analyse the differences in cutting procedures.
Bonding procedures are a prerequisite when using fiber posts. Another step of this thesis was to evaluate the efficacy of a technique (“one-shot”) -alternative to the well-established procedure- in forming resin tags, adhesive lateral branches and RDIZ when luting translucent fibre posts into root canal preparations. 

Fibre posts went through rapid developments in the last few years, in particular when dealing with the shape of the post. Interestingly, starting from the double-cylinder shape, endodontic shapes and then double tapered shapes were presented, as the adhesive cementation now relies on formation of resin dentin interdiffusion zone and resin tags (Ferrari et al 2002) even if the good fitting and mechanical retention of the post inside the root canal contribute to sliding friction as for non adhesive cements (Goracci et al 2004). As a matter of fact it is pretty common to face root canals that are not perfectly round after endodontic instrumentation. A study was conducted regarding the very last brand of fiber post available (Anatomic Post’n Core, RTD, St Egrève, France), that is able to reduce the cement thickness and to immediately restore the coronal portion in cases where the root canal is not round and a huge loss of tooth structure is present.

Finally a possible future use of fiber posts in combination with a direct resin restoration is examined for the restoration of root canal treated teeth, according to the aim of the minimal intervention philosophy.

1.1 Differences between healthy and root canal treated teeth

There is substantial literature stating that endodontically-treated teeth differ from teeth with a viable pulp (Ingle JA 1973, Walton R et al.,1996). As a matter of fact, tooth fractures often result in severe damages to non-vital teeth (Angmar-Månsson et al., 1969, Rud et al., 1970, Meister et al., 1980, Morfis, 1990, Testori et al., 1993, Bergman et al., 1989, Torbjöner et al., 1995, Fuss et al., 1999), and most likely, the only alternative therapy is extraction. Three main aspects can be analyzed regarding these differences after root canal therapy: 1) changes in the physical properties and in the chemical composition, 2) changes in the morphology and in the biomechanical behavior of teeth under stress, 3) possible elevation of pain threshold and loss of pressoreceptors.
1.1.1 Changes in the physical and chemical properties of the tissue

A vital tooth presents with a stiffer structure (enamel) and a more compliant support underlying it (dentin). Notwithstanding a fracture that can always occur, teeth usually exhibit microcracking of the enamel as a consequence of wear (tooth-to-tooth and tooth-to-food wear). Type I mineralized collagen fibrils are abundant within healthy dentin. Back in 1998, Nakabayashi and Pashley (Nakabayashi et al., 1998) demonstrated that these fibrils are able to retard the growth of microcracks (Sakaguchi et al., 1992), and that if they are removed after root canal treatment a fracture is more likely to occur. The main physical properties of dentin that were studied during the years were the modulus of elasticity, the tensile strength and the compressive strength. Unfortunately results differ a lot from tooth to tooth and within the same type of tooth (Peyton et al., 1952; Tyldesley 1959). The methods in which elasticity or the dentin hardness were measured have changed through time. Using a micro-indentation technique, Lewinstein et al. (1981) observed no difference in the elasticity and dentin hardness between vital teeth and teeth that were endodontically treated 5 or 10 years before (Lewinstein et al. 1981). Pashley et al. (1985) showed that the micro-hardness of coronal dentin is higher in superficial than in deep dentin. This decrease in hardness may be due to a decrease in the stiffness of the intertubular matrix (Kinney et al., 1996). Many techniques were used to measure the modulus of elasticity. Some studies reported values between 15 and 19 GPa (Sano et al., 1995; Van Meerbeek et al., 1993), while the ultimate compressive strength was around 300 MPa. When the microtensile test was used to measure the ultimate tensile strength of dentin, values around 100 MPa were reported (Sano et al., 1994). Irrigating solutions that are used in endodontics have been reported to have a negative effect on the physical properties of dentin. Micro-hardness is significantly reduced in root canal dentin after the use of H₂O₂/NaOCl and EDTA (Saleh et al., 1999). Different concentrations of NaOCl can also reduce tooth surface strain, even if no difference was found in the strain recorded after different irrigation regimes (Goldsmith et al., 2002). Chemical changes may also occur when a tooth is endodontically treated. Healthy dentin can be described as a “…biological composite of a collagen matrix filled with submicron to nanometer-sized calcium deficient, carbonate-rich apatite crystallites dispersed between
micron–sized hyper-mineralised, collagen-poor hollow cylinders…” (Marshall et al., 1997). Dentin is about 50% (vol.) mineral, 20% (vol.) water and 30% (vol.) organic matrix (LeGeros 1991), but the composition may change with position of the tooth and even within a tooth (Panighi et al., 1993). Age or disease can affect the composition: coronal dentin has approximately twice the number of tubules of radicular dentin and also less inorganic substrate and less intertubular dentin, while radicular dentin contains less moisture. A 9% lower moisture content was found in pulpless dog teeth when compared with vital dog teeth (Helfer et al., 1972). A later study (Huang et al., 1992) showed that dehydration of human dentin increased its Young’s modulus and that wet dentin specimens from treated pulpless teeth generally showed lower elastic modulus and proportional limit in compression than those of normal teeth. Using a method of collagen dissolution, Mason (2001) demonstrated that the percentage of collagen present in crown and root dentin decreases after the root canal treatment. The percentage of collagen in crown dentin of healthy teeth is 21.7%. The value was reduced to 20.1% in teeth that had been endodontically treated for 2 years, and was further reduced to 16.8% in teeth that had been endodontically for 10 years. In root dentin the percentages are 25.5%, 23.5% and 19.3% respectively. Moreover, a degradation of resin composite and depletion of collagen fibrils were observed in specimens that were aged in an oral environment (Hashimoto et al., 2000). These findings were further confirmed in a recent transmission electron microscopy study, showing a decrease in the distribution of the collagen fibrils within root dentin 5 years after endodontic treatment (Ferrari et al., 2004).

1.1.2 Changes in the morphology and in the biomechanical behavior of teeth under stress

In 1976, Tidmarsh described the intact tooth as a “…hollow, laminated structure that deforms under load; this structure may undergo permanent deformation following excessive or sustained loads…” (Tidmarsh 1976). In his PhD thesis at the University of Otago, Grimaldi showed that there is a “…direct relationship between the amount of central tooth structure lost in cavity preparation and the deformation under load….after endodontic access preparation the tooth can deform to a greater extent
under applied load and thus be more susceptible to fracture. It might therefore be expected that the removal of dental substance during access cavity preparation and cleaning and shaping procedures would significantly weaken the tooth…” (Grimaldi 1971). On the other hand, in a study comparing MOD cavity preparation with simple access opening and endodontic procedures in maxillary second premolars, the reduction in tooth stiffness was 60% versus 5% (Reeh et al., 1989). The highlights the importance of preserving the marginal crest as a structure that can compensate for the stresses generated by the occlusal and chewing forces. Other structures, such as the presence of intact roofs of pulp chambers, are also important in avoiding root fractures in a healthy tooth (Fuzzi 1993). Usually, pulpless teeth have lost substantial coronal and radicular tooth structure from pre-existing restorations, dental caries, and access cavity preparations (Morgano et al., 1993). The endodontic procedure in itself can also be an explanation for additional morphological changes. Excessive flaring during endodontic treatment and poor gutta-percha condensation procedures were considered as possible causes of root fracture (Trabert et al., 1978, Milot et al., 1992). The introduction of NiTi rotary instruments has led to great improvements in the effectiveness and speed of root canal instrumentation, and a more conservative approach is universally adopted in order to reduce the amount of tooth structure that has to be eliminated during the root canal treatment. These instruments allow faster (Schafer et al., 2001, Gambill et al., 1996, Glosson et al., 1995), more centered (Gambill et al., 1996, Glosson et al., 1995, Bertrand et al., 2001), rounder (Gambill et al., 1996, Glosson et al., 1995) and more conservative (Schafer et al., 2001, Gambill et al., 1996, Glosson et al., 1995) shapings of the root canals than stainless steel instruments.

1.1.3 Possible elevation of pain threshold and loss of pressoreceptors.

Another possible cause of weakness of endodontically-treated teeth might be the loss of pressoreceptors. There is no clear evidence about this topic. When pain thresholds of vital and endodontically-treated teeth were analysed with a minimal load (Lowenstein et al., 1955), it was found that the load thresholds were 57% higher in endodontically-treated teeth compared to vital teeth. An autoradiographic study of the sensory innervation of rats’ teeth (Pimenidis et al., 1977) showed the
presence of structures similar to corpuscular receptors in the pulp, thereby suggesting that those tissues may be responsive to modalities other than pain, such as pressure. Another study (Linden 1975) did not support this hypothesis. More recent studies on the reflex control of human jaw-closing muscles suggested the role of periodontal and gingival receptors as potential pressoreceptors (Louca et al., 1996, 1998).

In conclusion, the general loss of tooth structure in the non-vital tooth, together with the alterations in collagen distribution, may simultaneously contribute to the increased susceptibility of endodontically-treated teeth to fracture under loading. A further reduction in micro-hardness can be induced by the use of irrigating solutions during endodontic treatment. The loss of water, the increase in deformation due to the loss of load-supporting structure, and the generation of micro-fractures by gutta-percha condensation procedures may also contribute to the weakness reported in endodontically-treated teeth.

1.2 Relation between fracture resistance of the endodontically-treated teeth and presence of posts

It is a common belief that the likelihood of survival of a pulpless tooth is directly related to the quantity and quality of remaining tooth structure (Assif et al., 1994, Guttman, 1992, Cohen et al., 1996). For many years, the concept of using a post for the restoration of endodontically-treated teeth was based upon the philosophy that the post would “reinforce” the tooth, and that additional retention was needed for the core restoration. A post was generally placed in an attempt to strengthen the tooth. However, as dentin has to be sacrificed, especially when a metal post is utilized, and in consideration of other aspect that will be analyzed later, a post does not strengthen the root, but serves solely to improve retention of the core (Lloyd et al., 1993, Sorensen et al., 1990, Morgano et al., 1996, Abou-Rass, 1992). Resistance to fracture of the non-vital tooth is related with the thickness of remaining root dentin, especially in the bucco-lingual direction (Guzy et al., 1979, Mattison, 1982, Tjan et al., 1985). Several factors have been identified (Stockton, 1999, Morgano et al.,
1999), in both clinical or laboratory studies, to affect the fracture resistance and the failure modes of post-core restorations.

An important factor is the type of tooth and its position in the dental arch. It was found that half of the fractured post-retained teeth were maxillary second premolars (27.2%) and mesial roots of the mandibular molars (24%). The susceptibility of these teeth to root fracture increased when the residual sound tooth structure was less than 1-2 mm (Pilo et al., 1998, 2000; Tamse et al., 1999). Moreover, oval-shaped canals are more prone to root fracture, as there are more spaces that have to be filled with luting cements. As the cement dissolves, spaces are inadvertently created for the post to move inside the dowel space. These micro-movements may eventually result in dislodging of the post, fatigue of the tooth and root fracture (Chapman et al., 1985).

Post length is important as well. Many different recommendations have been given to clinicians regarding this issue (one half, two thirds, three quarters of the root, below the cemento-enamel junction, as long as possible…etc). Sorensen and Martinhof (1984a, 1984b) reported a high risk of tooth fracture for teeth with short posts, while other studies indicated that long posts can affect root resistance because of the removal of tooth structure in the deepest part of the root itself (Guzy et al., 1979).

Besides the length, the diameter of the post is also significant. This is related to the remaining tooth structure. As an increase in post diameter did not provide in increase in post retention, conservation of remaining tooth structure by avoiding the use of posts with a large diameters have been recommended (Standlee et al., 1978; Guzy et al., 1979; Standlee et al., 1980).

Three basic types of clinical study are able to provide information on the incidence of root fracture in endodontically-treated teeth. They include surveys of root fractured extracted teeth, retrospective studies on the fracture rate of endodontically-treated restored teeth, and prospective studies on the fracture rate of certain types of restorations of endodontically-treated teeth.

Initially, corrosion was cited as a cause of root fractures (Angmar-Månsson et al., 1969; Rud et al., 1970). In these papers maxillary premolars accounted for 61.5% of the total number of root fractures, the mandibular premolars accounted for 16.3%,
and the other tooth types ranged from 0.4% for mandibular incisors to 5.4% for the first mandibular molars. These percentages may be partially caused by the observation that some teeth are endodontically treated and restored with posts less frequently than others, and by the fact that molars were more commonly extracted in the era in which these studies were conducted. High percentages of endodontically-treated fractured premolars, 56% and 52% respectively, were also found in two more recent surveys of 36 (Testori et al., 1993) and of 92 vertically fractured teeth (Tamse et al., 1999). The mesial roots of mandibular molars were also frequently extracted because of root fractures (Tamse et al., 1999). Among all the surveys of tooth extraction due to root fracture, only the study of Testori et al. (1993) included a statistical analysis of the results. A significantly higher incidence of fractures in premolars and molars was found. But the majority of studies available on the root fractures of endodontically-treated teeth are retrospective in nature (Hansen et al., 1990a, 1990b; Walton, 1997, 1999). The studies by Sorensen and Martinoff (1984a, 1984b) are often cited when debating this topic. Their conclusions were that coronal coverage did not significantly improve the rate of clinical success for anterior teeth while it improved the rate of clinical success for premolars and molars. Among teeth restored with posts, the parallel-sided serrated dowel with an amalgam or resin composite core recorded the highest success rate. The tapered cast dowel and core displayed a higher failure rate than teeth treated without intracoronal reinforcement. The parallel-sided serrated dowel did not have failures caused by root fracture, whereas root fractures caused extractions of teeth restored with tapered cast dowels and cores. The success rate of teeth with a dowel length equal or greater than the crown length exceeded 97%. One of the authors’ conclusions was that “…a post did not significantly strengthen endodontically treated teeth…”. Unfortunately no prospective studies are available to definitely validate all the aspects analyzed. More prospective studies are required to evaluate post-core restorations in controlled clinical situations.
References


Lowenstein NR, Rathkamp R. A study on the pressoreceptive sensibility of the


Mason PN. Transactions of International ADM meeting, Siena 2001.

Mattison GD. Photoelastic stress analysis of cast-gold endodontic posts. J Prosthet

Meister F, Lommel TJ, Gerstein H. Diagnosis and possible causes of vertical root

Milot P, Stein RS. Root fracture in endodontically treated teeth related to


Morgano SM. Restoration of pulpless teeth: application of traditional principles in

Morgano SM, Brackett SE. Foundation restorations in fixed prosthodontics: current

Morgano SM, Milot P. Clinical success of cast metal post and cores. J Prosthet Dent
1993; 70:11-6.

Nakabayashi N, Pashley DH. Hybridization of dental hard tissues Berlin:

Panighi M, G’Sell C. Effect of the tooth microstructure on the shear bond strength

Pashley DH, Okabe A, Parham P. The relationship between dentin microhardness

1952;31: 366-70.

Pilo R, Corcino G, Tamse A. Residual dentin thickness in mandibular premolars

Pilo R, Tamse A. Residual dentin thickness in mandibular premolars prepared with

Pimenidis MZ, Hinds JW. An autoradiographic study of the sensory innervation of

Reeh ES, Messer HH, Douglas WH. Reduction in tooth stiffness as a result of


Chapter 2 The use of fiber posts in dentistry

2.1 The use of fiber posts
The potential of fiber reinforced materials in restorative dentistry has been appreciated for some time (Bradley et al., 1980). With the introduction of fiber posts (Duret et al., 1990a; 1990b, 1992), a new trend has been established, in the restoration of the endodontically-treated teeth. Fiber posts can be considered as composite reinforced materials. A composite is “any material that is composed of hard, pebble-like filler particles, surrounded by a hard matrix of a second material, which binds the filler particles together” (Vichi A et al., 2002). The purpose of making composite structures is to obtain better mechanical characteristics with the final material when compared to the single components. As far as fiber posts are concerned, fibers are embedded in a matrix of epoxy-resin, and an interfacial agent such as silane is used to optimize the link between the two components.

2.2 Fabrication process and structure of fiber posts
To manufacture fiber-reinforced post, the first step is to produce cylindrical barrels and then these barrels are machined into different shape and diameter. Pultrusion is the name for this process, frequently it is a continuous and semi-automated process. Resin-impregnated fibers are pulled through a series of forming dies. The final die is heated to cure the resin, thereby producing a rigid composite section. The profile is determined by the die cross-section which could be round, rectangular, square or a variety of other shapes. The section produced can either be cut into discrete lengths after the puller system or wound onto a drum. The speed of travel through the die is determined by the viscosity, thickness and curing of the resin. The process uses a hardened (hard-chromed) steel die and a pultrusion machine (Fig 1).
The benefits of this process are increased strength/stiffness of the final product, especially if compared to the two single components alone. High pressure and temperatures densify the composite, further impregnating the fibers and eliminating voids. This process offers a high fiber to resin ratio, which translates directly into superior strength characteristics of the fiber-reinforced material. Any variation in pressure and temperature values during the process may result in variation of the mechanical properties of the material. Finally, a post is fabricated that is composed of fibers (carbon i.e., 66% in weight, diameter of the single fiber around 10-15 microns) and filler (i.e. epoxy resin, 33% in weight). Fibers can be pre-treated with a silane-coupling agent to obtain a chemical bond between the fibres and the resin. This applies to glass, quartz and even carbon fibers. As a matter of fact fibers must be treated just after their manufacturing. Otherwise it is impossible to work with because fibers will be in all direction, not assembled. They will stick and will not have enough rigidity for handling (just like a roving of cotton). And one the goal of the treatment is to allow fibers to be handled, stored in roving. The addition of silane during the pultrusion process gives more stability to the system, and is the key factor for success in manufacturing. The importance of this topic will be discussed in chapter 4. In general, the addition of silane-coated glass fiber to BIS-GMA resin increases the elastic modulus, tensile and compressive strengths compared with non-treated fibers. The use of carbon fibers for the reinforcement of polymethylmethacrylate used for the construction of denture bases was first suggested by Schreiber in 1971. When a fiber post is manufactured, the “composite”
that is formed is anisotropic: as a consequence mechanical properties differ according to the direction of measurement.

2.3 Structure and mechanical properties of fibre posts

The Composipost (RTD, St Egrève, France) is the most studied carbon-fiber post. It was described by its inventors as a post fabricated from continuous, unidirectional high performance, pyrolytic carbon fibers, 8 µm in diameter uniformly embedded in an epoxy-resin matrix (Duret et al., 1990a, 1990b). The fibers constitute 64% by volume of the post. A coupling agent, that is usually called “silane”, is used to link the fibers to the epoxy resin matrix. It is usually a mixture containing silane but not only silane (with wetting agent, coupling amino agent for example). “Silane” is a general word”. A silane is a chemical component with two extremities (at least), one is really silane (OH) and the other is epoxy if the manufacturer wants to use it with epoxy resin. But this extremity can be methacrylate when the resin matrix is methacrylate. Definitely the “silane” must be selected to be suitable with the resin matrix. This “silanisation” is made by the manufacturer at a temperature of 160-180°C. There’s first a heat treatment and then a chemical treatment to fix coupling agent (like silane). Manufacturers do not give much details but the first treatment is a physical treatment to enhance the power of the silanisation.

The epoxy resin matrix is injected into the pre-tensioned fiber bundle. The original Composipost was not radio-opaque; the radio-opacity was obtained in the second generation of these posts (Composipost Radio-opaque, RTD) by the injection of a high-molecular weight element powder into the un-polymerized post structure.

Many different types of carbon, quartz, silica-zirconium and glass fibers are now available in the market: carbon was the first material used for manufacturing fiber posts. These posts represented the first true alternative to cast post and cores, and to pre-fabricated metal posts.

The following chart shows the mechanical properties of these kinds of posts.

<table>
<thead>
<tr>
<th>COMPOSIPOST</th>
<th>No radiopaque</th>
</tr>
</thead>
<tbody>
<tr>
<td>TENSILE STRENGTH*</td>
<td>2900 MPa</td>
</tr>
<tr>
<td>TENSILE MODULUS OF ELASTICITY* AT 30°</td>
<td>17-18 GPa</td>
</tr>
<tr>
<td>FLEXURAL STRENGTH**</td>
<td>1900 MPa</td>
</tr>
<tr>
<td>FLEXURAL MODULUS OF ELASTICITY**</td>
<td>135 GPa</td>
</tr>
<tr>
<td>INTERLAMINATE SHEAR STRENGTH**</td>
<td>65-95 MPa</td>
</tr>
</tbody>
</table>

* values determined by calculations. ** values determined by testing raw material
The use of glass and quartz fibers was initially proposed as an alternative to the dark colour of carbon posts. Even though a ceramo-metal crown, and often even a full ceramic crown is able to mask the dark colour of the post underlying the restoration (Vichi et al., 2000), “esthetic” posts eventually gained popularity (Ferrari et al., 2001). Moreover, during the preparation of the abutment (when a carbon fiber post was selected), a dark powder was spread all around the mouth of the patients, who sometimes complained because of this fact. As far as esthetics is concerned, several brands of translucent glass fiber posts are available. They are better accepted than carbon fiber posts, especially for anterior roots that provide support to all-ceramic coronal restorations. The mechanical behaviours of these newer generations of posts do not seem to differ from the first generation of fiber posts (Mannocci et al., 1999; Grandini et al., 2004). By further adding a component usually in the resin matrix, radiopaque posts can be obtained. Finally, translucent fiber posts are now available to be used in combination with a dual curing resin cement and to take advantage of light passing through the post for polymerization.

2.4 Metal posts versus fiber posts

The technique for the preparation of cast post and cores requires the clinician to prepare the dowel space in order to finally have a length equal to two thirds of the root, a width equal to one third of the root and 3-4 mm of root canal filling left at the apex of the root (Shillimburg et al., 1982). In the last decades many opinion leaders stressed the fact that a well-performed cast post and core could work for years (Shillimburg et al., 1982). However, this kind of restoration has a failure rate ranging from 6 to 10% in the literature (Morgano et al., 1993, Sorensen et al., 1984, Torbjoner et al., 1995). Failure rate can even be worse as far as pre-fabricated metal posts are analyzed (Tjan et al., 1985, Fuss et al., 1999). It was previously thought that in order to achieve success with post-retained restorations, the post had to be as strong, as long and as stiff as possible (Shillimburg et al., 1982, Sorensen et al., 1984, Morgano et al., 1993, Torbjoner et al., 1995). However, metal posts can only be successful if they do not overpass the elastic limit of the dentin (Desort et al., 1983, Leary et al., 1987). As “…retention often requires the removal of tooth structure…it is a procedure that may reduce the strength of the root…when placing a
post, the dentist must evaluate each tooth individually to determine the best approach to obtaining the *maximal* fracture resistance...” (Stockton, 1999). In a study comparing cast post and cores and carbon fiber posts, 200 patients were examined. The failure rate for cast post and cores (Group 1, high modulus restorations in terms of modulus of elasticity) and fiber posts (Group 2, low modulus restorations) was totally different. Group 1 had 84% clinical success, 2% excluded for non-compliance, and 9% root fracture (no need to underline), 2% dislodgement of crown, 3% endodontic failures. Conversely Group 2 had 95% clinical success, 3% excluded for non-compliance, 2% endodontic failures. The difference between the two groups was highly statistically significant (Ferrari et al., 2000). For this reason, clinical acceptance of fiber posts is now higher than it was before. The advantage of having no root fracture is very important. Failure can occur as a “debonding” of the post, especially at the time of removing the temporary restoration, but this failure can easily be dealt with by repeating the adhesive procedures. When fiber posts and a core and metal posts and a core were compared, it became more and more obvious that the first ones functioned more satisfactorily. As far as the mechanism of failure is concerned, metallic posts on failure tend to produce an irreversible root fracture. Conversely, in the presence of a fiber post, root fracture that occurs is usually located more coronally and is more easily retreatable (Reagan et al., 1999, Ukon et al., 2000, Cornier et al., 2001). This type of failure may be due to the wider amount of tooth structure must be sacrificed when a metallic post is placed (Stankiewicz et al., 2002). Two recent papers underlined the concept mentioned above: even if a crown is made, when a failure occurs, favorable fractures are seen in teeth restored with fiber posts and resin cores, whereas unfavorable fractures or failures are usually encountered with the use of a metal post, or a fiber post of bad quality (Heydecke et al., 2002, Akkayan et al., 2002).

2.5 *Role of the final restoration design (ferrule effect)*

It is known that post luting in a way brings to the transportation of stresses in the root canal and eventually to vertical root fractures (Guzy and Nicholls 1979). Coronal coverage has always been considered a very important factor for preventing root fractures in endodontically treated teeth (Frank 1959). Many years ago it was
suggested (Rosen 1961) that a sub-gingival collar might provide an extra-coronal bracing able to prevent fractures of the root. The term “ferrule effect” was used for the first time in 1987 by Eissman and Radke and it indicates a 360-degree ring of cast metal that embraces the tooth.

A ferrule is defined as a metal ring or cap used to strengthen the end of a stick or tube (Glossary of Prosthodontic terms). The effect of a metal collar on stress distribution with cast post and cores was studied by using three-dimensional photoelastic models of maxillary canine teeth of average dimensions. Standardized parallel post and cores cemented into the models were used, with half of the samples incorporating a 1.5 mm metal collar, and a 400 gm load was applied to the cingulum of the cores. Stresses were then calculated and, on a point by point basis, a better distribution was found in the collared specimens (Loney et al 1990). Another simulation study was designed to compare the effect of different corono-radicular reconstruction methods on stress transmission to dental tissues. Whatever the type of stress (tensile or compressive), the greatest stress was observed in the cervical region, regardless of the model. The absence of a cervical ferrule was found to be a determining negative factor, giving rise to considerably higher stress levels. Nevertheless, the peripheral ferrule seemed to cancel the mechanical effect of the reconstruction material on the intensity of the stresses. Moreover, when a ferrule effect was achieved, the choice of reconstruction material had no impact on the level of cervical stress (Pierrisnard et al 2002). In another in vitro study it was demonstrated that increasing the ferrule length of the endodontically treated teeth from 1 mm to 1.5 mm in specimens restored with quartz-fiber and glass-fiber dowels did not produce significant increases in the failure loads. No significant difference was detected between glass-fiber and glass-fiber plus zirconia dowels with 1.5-mm and 2.0-mm ferrules. However, fracture thresholds were higher for all 4 dowel systems tested in the study when the specimens were prepared with a 2.0-mm ferrule length (P<.001) (Akkayan 2004). Also among clinicians the ferrule effect was perceived as an important factor; responses to a questionnaire sent to 1000 dentists in Switzerland showed that most of the answering dentists strove to stabilize the remaining tooth structure by circular enclosure of the tooth structure by the later crown (ferrule effect) (Tinner et al 2001). In a recent literature review Stankiewicz
underlined that a ferrule effect occurs owing to the artificial crown bracing against the dentine extending coronal to the crown margin. Overall, the author concluded that a ferrule is desirable, but should not be provided at the expense of the remaining tooth/root structure. (Stankiewicz et al 2002). Another important factor is the height of the remaining tooth structure between the core and the crown margin: this is a much more significant factor in determining the fracture resistance of teeth (Hunter et al 1991). For this reason the crown lengthening surgical procedure has been taken into account to obtain a consistent height of the remaining tooth structure and eventually a desirable ferrule effect (Gegauff 2000).

In conclusion, a ferrule effect is desirable when restoring compromised endodontically treated teeth. Crown lengthening can be considered as one of the therapeutic options, and a positive crown/root ratio is an important factor for predicting success of the treatment.
References


Success in endodontic treatment is a key factor to allow success in the restoration of root canal treated teeth. A well performed endodontic treatment is based on the removal of debris and organic material inside the root canal (Castellucci 1993) and on the mechanical preparation of the canal itself to receive an obturation material (Ingle 1993). The importance of apical seal has been already underlined in the literature (Walton et al 1996). More recently coronal seal has acquired the same importance, and many authors concluded that exposure to the oral cavity of a well performed endodontic treatment (not preventing from coronal leakage) inevitably brings to a re-infection and in conclusion to a failure (Madison et al 1987 and 1988, Swanson et al 1987). In 1985 Saunders evaluated the long-term coronal leakage in root fillings achieved by 2 gutta-percha techniques using 2 calcium hydroxide-containing sealers. Coronal leakage was then determined with an India ink tracer and a clearing technique. The extent of coronal leakage was measured with a magnification device and the authors concluded that all the techniques analyzed were subjected to extended leakage (Saunders et al 1985). In another study three common sealers were evaluated for coronal leakage using an animal model in vivo. After 45 days exposure to the oral cavity, none of the sealers was capable of preventing leakage and coronal dye penetration (Kopper et al 2003).

The detrimental effect of eugenol on adhesion of resinous cements has been taken into consideration (Tjan et al 1992, Schwartz et al 1998). Resin composites polymerise by the addition of free radicals; this process may be inhibited by phenolic compounds, such as eugenol (2-methoxy-4-allyphenol) that is contained in the vast majority of endodontic sealers and temporary filling materials, and can penetrate into the root canal walls (Kielbassa et al 1997). The contact of eugenol with the dentinal walls significantly altered the dentin penetration of dentin bonding system (Mayer et al 1997). For these reasons the persistence of eugenol into the root canal walls has been advocated as a cause of some inconsistent results of posts cemented with adhesive resins. Unfortunately, the results of the studies about post retention are not reliable because they were performed on root canals that were different in shape and sizes. As a consequence it is not possible to establish whether
the force needed to remove the post was the result of adhesion of the cement to root
dentin or of the different degree of adaptation of the post to the varying
morphologies of the root canals of the teeth used. The adhesive strength of resin
composites to tooth structure may be simply influenced by the cleanliness of tooth
surface; in two recent investigations (Watanabe et al 1997) on temporary cement
remnants as adhesion inhibiting factors in the interface between resin cements and
bovine dentin, the temporary cement application significantly decreased the tensile
bond strength of all adhesive systems employed. The contamination with various
agents of enamel and dentin surface lowered the bond strength of resin composite
restorations performed with different bonding agents (Xie et al 1993). Both eugenol
containing and eugenol free temporary cements decreased the tensile bond strength
of resin luting cements to bovine teeth (Terata 1993). No difference was reported in
leakage of resin luted inlays when the cavity preparations were treated with either
eugenol-containing or eugenol-free temporary cements (Woody et al 1992).

Definitely, as the effect of eugenol is generally limited to superficial dentin, and as a
certain removal of tooth structure always happens during preparation for post
placement, it is likely to happen that the eventually inhibited layer is removed, and a
lack of adhesion can be explained differently. The preparation for post placement
can be performed in two ways: with hot pluggers and with burs (Ferrari et al 2003).
Burs are usually preferred as they are faster and allow a higher removal of debris,
leaving a cleaner dowel space where adhesive luting can be performed. Recently
Serafino evaluated the cleanliness of root dentin walls after mechanical preparation
and etching procedure. All the tested procedures showed a clean walls’ surface.

Pieces of guttapercha remained along the canal walls where the drill shape did not
follow the root canal shape. Endodontic cement and small amount of guttapercha
were noted closing dentinal tubules in some areas of the root walls (Serafino et al
2004). It is obvious then that high accuracy has to be put when preparing the dowel
space, and that a rotating brush could improve the cleanliness of the post space. But
the starting point is always that the endodontic procedure has to be well performed if
we look for success in restoring root canal treated teeth. The following SEM study
regards different irrigating regimes used during endodontic treatment to achieve a
clean root canal before guttapercha condensation procedures.
3.1 Evaluation of Glyde File Prep in combination with sodium hypochlorite as root canal irrigant: a scanning electron microscopic study.

It is well known that the irrigation of the root canal plays a critical role in the determination of success in endodontic therapy (Walton et al. 1996). Several studies demonstrated that the quantity of debris found after instrumentation is higher in canals prepared without irrigating solutions than in cases where irrigating solutions have been used (Goldman et al., 1981). Even in canals where a proper preparation had been performed, Davids et al. (1972) experimentally demonstrated that there were not instrumented areas where organic and inorganic debris could be found. On the other hand, dentin instrumentation always causes the formation of a thin smear layer which recovers the whole surface of the root canal. Ostby (1957) was the first one to use EDTA as an irrigating solution, with a chelating action, to remove the inorganic component. With the same purpose, solutions of sodium hypochlorite have been later proposed, varying the concentration from 2% to 5% (Mc Comber et al. 1975, Branstrom et al. 1974, Pashley et al. 1981). So far, EDTA was considered the best irrigating for removing the inorganic component of the smear-layer and, in association with sodium hypochlorite, showed the best results (Goldman et al. 1984, Aktener et al. 1993).

Different morphological observations can be performed to evaluate smear layer and remained debris after endodontic instrumentation and irrigation of the root canal (Peters et al. 2000). Barbakov et al. (1998) proposed a quantitative evaluation of smear layer and debris presence along root canal walls, based on serial photomicrographs placed next to each other, forming a continuous horizontal examination strip at three levels (2-, 6-, 10-mm from the apex) of the canal walls. Recently, a new chelating agent (Glyde File Prep, Dentsply-Maillefer, Ballaigues, Switzerland) containing EDTA has been proposed.

The aim of the present study was to evaluate 1. the smear layer, debris and tubule orifices of root canal walls after being instrumented and irrigated by Glyde File Prep and 2. the null hypothesis that different irrigating techniques cannot determine any difference on amount of debris along root canal walls.
3.2 Materials and Methods
Forty mandibular anterior teeth (incisors and canines), stored in 0.1% thymol, were randomly selected for this study from the department’s stock of extracted teeth. Canal morphology was verified from radiographs (70 kV and 0.08 s) taken both buccolingually and mesiodistally (Kodak, USA). The crowns were resected to ensure good visibility of the canal and optimal access.

Final working lengths were set by deducting 1 mm from lengths recorded when tips of size 10 or 15 K-files (Dentsply-Maillefer, Ballaigues, Switzerland) were visible at the apical foramina. All working lengths were confirmed radiographically. The coronal 3 to 4 mm of the canals were prepared with Gates-Glidden burs (sizes 2 through 4). The teeth of all groups were shaped with Ni-Ti (Profile 0.4-0.6 – Maillefer) instruments. The instrumentation was performed exactly according to the manufacturer’s instructions. ProFile (PF, Dentsply-Maillefer) instruments were used in a modified crown-down approach after using Gates-Glidden burs and the step-down technique. The coronal two-thirds were enlarged using PF sizes 5, 4 and 3, sequentially. The size 2 instrument was used in most canals, but the size 1 PF was not used at all. Apical preparations were then completed using nos. 3, 4, 5 and 6 PF instruments. Finally, canals were stepped-back using PF instruments nos. 7, 8 and 9. Each set of PF instruments was discarded after preparing 10 canals.

The specimens were randomly assigned to four equal groups of 10 each (Table 1).

Table 1: Type of irrigant used in the different groups

<table>
<thead>
<tr>
<th>Group</th>
<th>Irrigant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group A</td>
<td>Physiological solution</td>
</tr>
<tr>
<td>Group B</td>
<td>NaOCl 2.5%</td>
</tr>
<tr>
<td>Group C</td>
<td>NaOCl 2.5% and GFP</td>
</tr>
<tr>
<td>Group D</td>
<td>NaOCl 2.5% and GFP (PP)</td>
</tr>
</tbody>
</table>

Legends: NaOCL= Sodium Hypochlorite, GFP= Glyde File Prep, PP= Paper points

All canals were flushed with 10 ml of the test irrigant using disposable syringes and 27-gauge needles. The total time of irrigation has been 30 minutes per canal. Group A was irrigated with physiological solution; Group B with sodium hypochlorite 2.5%; Group C with sodium hypochlorite 2.5% and Glyde File Prep alternately. Group D was irrigated with sodium hypochlorite 2.5% during the preparation, the
root canals were then dried and Glyde File Prep applied with sterile paper points (Mynol) and left for five minutes. At the end a further irrigation with sodium hypochlorite 2.5% was performed. It must be noticed that in Group C Glyde File Prep has been used following manufacturer’s instructions, while in Group D a modified technique has been performed. In Group C Glyde File Prep was used alternating it as irrigant with sodium hypochlorite during the preparation. In Group D, instead, only sodium hypochlorite was used during the preparation, and after that Glyde File Prep was applied with a paper point and left for five minutes. At the end a further irrigation with sodium hypochlorite was performed.

After preparing the canals, the teeth were sectioned along their buccal and lingual surfaces, using a low speed diamond saw (Isomet, Buhler, Lake Bluff, NY, USA). The root halves were coded and examined in a stereomicroscope (Nikon, Germany). The coded, halved specimens were then dried, mounted on metallic stubs, gold-sputtered (Balzers CSD 030, Balzers, Liechtenstein), and evaluated using a scanning electron microscope (SEM) at low (x10 and x 15) and higher (x200 and x500) magnifications (Philips, 515, Amsterdam, The Netherlands) at the apical, middle and coronal levels. Serial SEM photomicrographs at x500 original magnification were taken of the canal walls at the 2-, 6-, and 10-mm levels. The serial photomicrographs were placed next to each other, forming a continuous horizontal examination strip at three levels (Fig. 1). Irrespective of the number of photomicrographs needed to form a complete strip, each strip was subdivided into eight “assessment units” (Barbakow et al 1998).

The amounts of debris, smear layer and the visibility of open tubules were rated using a 4-step scale method by the same person (M.F.) who was unaware of the coding system to exclude observer bias. Evaluation was repeated twice for the first 20 specimens to ensure intraexaminer consistency. The amount of debris present at x500 magnification was graded between 0 and 3 (Table 2a).

Table 2a: Debris scores

<table>
<thead>
<tr>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No debris</td>
</tr>
<tr>
<td>1</td>
<td>Few debris particles, with a diameter &lt; 20 microns</td>
</tr>
<tr>
<td>2</td>
<td>Many debris particles, with a diameter &lt; 20 microns</td>
</tr>
<tr>
<td>3</td>
<td>Many debris particles, with a diameter &gt; 20 microns</td>
</tr>
</tbody>
</table>
A debris score of 0 was assigned when no debris was present. A score of 1 was assigned when few debris particles were present, whose largest diameter was less than 20 microns. A score of 2 was recorded when large quantities of debris particles were present, whose diameter was less than 20 microns. A score of 3 was assigned when large amounts of debris particles were present, whose diameters were greater than 20 microns in any direction. The amount of smear layer and the opening of the dentinal tubules were graded between 0 and 3 (Table 2b).

**Table 2b: Smear layer and dentinal tubules scores**

<table>
<thead>
<tr>
<th>Score</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>Open dentinal tubules. No smear layer nor calcospherites</td>
<td>Some open dentinal tubules. A thin smear layer is present</td>
<td>All dentinal tubules covered by a thin smear layer</td>
<td>All dentinal tubules closed by a thick smear layer</td>
</tr>
</tbody>
</table>

A score of 0 was assigned when all dentinal tubules were open and no smear layer was present or not instrumented calcospherites were noted. A score of 1 was recorded when some dentinal tubules were open and a thin smear layer covered the openings of the cut dentinal tubules. A score of 2 was recorded when all dentinal tubules were covered by a thin smear layer. A score of 3 was assigned when all the dentinal tubules were closed by a thick smear layer.

Mean debris, smear layer and open tubules scores were calculated for Groups A, B, C and D and statistically evaluated using the Kruskal-Wallis and Mann-Whitney *U* tests at p 0.001 level.

### 3.3 Results

The mean amounts of debris, smear layer and open tubules found at the 2-, 6- and 10-mm levels in the test groups are listed in Tables 3 and 4 respectively.

To indicate the distribution of the individual scores, medians are recorded for the debris, smear layer and open tubules in Tables 3 and 4 respectively.

Mean debris scores for Group A and B were significantly higher than those found in Groups C and D. Lower debris scores were recorded in Groups C and D, in those Groups in which Glyde File Prep was used (Table 3).
Table 3: Debris scores (The groups with the same letter did not show statistically significant differences).

<table>
<thead>
<tr>
<th>Group A</th>
<th>Scores</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apical level</td>
<td>/</td>
<td>/</td>
<td>1</td>
<td>9&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.9</td>
<td></td>
</tr>
<tr>
<td>Medium level</td>
<td>/</td>
<td>/</td>
<td>1</td>
<td>9&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.9</td>
<td></td>
</tr>
<tr>
<td>Coronal level</td>
<td>/</td>
<td>/</td>
<td>2</td>
<td>8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.8</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Group B</th>
<th>Scores</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apical level</td>
<td>/</td>
<td>/</td>
<td>4</td>
<td>6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.6</td>
<td></td>
</tr>
<tr>
<td>Medium level</td>
<td>/</td>
<td>1</td>
<td>4</td>
<td>5&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>2.4</td>
<td></td>
</tr>
<tr>
<td>Coronal level</td>
<td>/</td>
<td>2</td>
<td>4</td>
<td>4&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.2</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Group C</th>
<th>Scores</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apical level</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>3&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>1.9</td>
<td></td>
</tr>
<tr>
<td>Medium level</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>1&lt;sup&gt;c&lt;/sup&gt;</td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td>Coronal level</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>2&lt;sup&gt;c&lt;/sup&gt;</td>
<td>1.0</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Group D</th>
<th>Scores</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apical level</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>1&lt;sup&gt;d&lt;/sup&gt;</td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td>Medium level</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>2&lt;sup&gt;d&lt;/sup&gt;</td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td>Coronal level</td>
<td>6</td>
<td>2</td>
<td>2</td>
<td>2&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.6</td>
<td></td>
</tr>
</tbody>
</table>

Differences in the mean amounts of debris between Group A and the different irrigation regimes (Group B, C and D) were highly significant (p < 0.001).

Mean smear layer and open tubules scores for the four groups are listed in Table 4.

Table 4: Smear layer and open tubules scores (The groups with the same letter did not show statistically significant differences).

<table>
<thead>
<tr>
<th>Group A</th>
<th>Scores</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apical level</td>
<td>/</td>
<td>/</td>
<td>/</td>
<td>10&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Medium level</td>
<td>/</td>
<td>/</td>
<td>/</td>
<td>10&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Coronal level</td>
<td>/</td>
<td>/</td>
<td>/</td>
<td>10&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Group B</th>
<th>Scores</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apical level</td>
<td>/</td>
<td>2</td>
<td>3</td>
<td>5&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>2.3</td>
<td></td>
</tr>
<tr>
<td>Medium level</td>
<td>/</td>
<td>2</td>
<td>4</td>
<td>4&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.2</td>
<td></td>
</tr>
<tr>
<td>Coronal level</td>
<td>/</td>
<td>4</td>
<td>2</td>
<td>4&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.0</td>
<td></td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Group C</th>
<th>Scores</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apical level</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>2&lt;sup&gt;c&lt;/sup&gt;</td>
<td>1.3</td>
<td></td>
</tr>
<tr>
<td>Medium level</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>2&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>Coronal level</td>
<td>6</td>
<td>3</td>
<td>1</td>
<td>2&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.5</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Group D</th>
<th>Scores</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apical level</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>0&lt;sup&gt;de&lt;/sup&gt;</td>
<td>0.9</td>
<td></td>
</tr>
<tr>
<td>Medium level</td>
<td>5</td>
<td>4</td>
<td>/</td>
<td>1&lt;sup&gt;e&lt;/sup&gt;</td>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td>Coronal level</td>
<td>6</td>
<td>2</td>
<td>2</td>
<td>2&lt;sup&gt;e&lt;/sup&gt;</td>
<td>0.6</td>
<td></td>
</tr>
</tbody>
</table>
A high amount of smear layer and no visibility of tubules on the prepared canal walls were found when physiological solution was used as the only irrigant (Group A). Mean amounts of smear layer scores in Group A reached the maximum score of 3. When sodium hypochlorite 2.5% was used (Group B) as irrigant, the samples showed less smear layer and more open tubules compared with Group A samples. When Glyde File Prep was used, in both tested techniques, the lowest scores were noted, and Group C and D had significantly less smear layer and more open tubules on the canal walls at the apical, mid-third and coronal levels, respectively, compared with Group A and B samples. Although there is not a statistically significant difference between Group C and D, Group D showed better scores than Group C.

3.4 Discussion

Smear layer is produced every time a canal is instrumented. The smear layer, which is mainly inorganic, is also made up by a slight organic component (proteinic agglomerates, vital or non-vital pulp tissue, odontoblastic processes, bacteria and blood cells)\(^{(2,5)}\). The thickness and composition of smear layer can vary depending on the kind of dentin and the instruments used (Mader et al 1984, Davis et al 1972, Mc Comb et al 1975). The smear layer can be organized in two layers: superficial smear-layer, made up by a 1-2 microns layer above the intertubular dentin, adhering on it and becoming indistinguishable from it, and smear-plugs within dentinal tubules, deepening for about 2-40 microns with a fingerlike or small-tube segments aspect (Mader et al 1984).

There is a rich but conflicting scientific data regarding the choice between removing or leaving the smear-layer from the dentinal wall. Some authors reported that the smear layer remaining on the canal walls should have two positive effects: to reduce the dentin permeability (about 40%) and to block the way through the tubules for bacteria and endotoxins in a mechanical way (13,14). Other authors emphasize the need of creating smear free canalar surfaces. Brannstrom e Nyborg (1974) demonstrated that the smear-layer can give shelter to anaerobic microorganisms, thus creating a chronic focus of irritating substances. In 1982 Akpata and Blechman (1982) confirmed the smear layer permeability to streptococcus. Moreover Williams and Goldman (1985) demonstrated that the
smear-layer can slow, but not block the way of microorganisms through the dentinal tubules. In 1993 Nissan et al. (1993) noticed that bacterial products, such as polysaccharidic endotoxin, can easily permeate human dentin, even when smear-layer was present. Besides it is known that the smear-layer negatively affects the adaptation of the materials used to fill the canal, and reduces the diffusion through the tubules, and as a consequence the efficacy, of many intracanal medicaments. Nevertheless smear-layer has the potential to harbor microorganisms: the choice of eliminating the smear-layer is essentially derived from the need of sealing the open dentinal tubules. (Behrend et al 1996, Goldman et al 1984).

Usually microscopic investigations are performed under laboratory conditions in order to predict the clinical behavior of new irrigating solutions. Unfortunately, SEM evaluation do not permit numeric data collection and consequently statistical analysis. Only a few studies have reported on quantitative evaluation of morphological observations of root canals (Peters et al 2000, barbakow et al 1998). In this way, a repeatable method was introduced.

The results of this study confirm that the irrigation with sodium hypochlorite alone is not able to totally remove the smear-layer, as its action is mainly directed to the organic debris. In order to obtain the total removal of the smear-layer, both organic and inorganic components, the combined use of sodium hypochlorite and EDTA is recommended (Group C and D) (Aktener et al 1993, Dippel et al 1984). The chelating agent somehow “prepares” the canal walls surfaces so that irrigants and medicaments are really effective with their anti-bacterial action.

The role of EDTA during the instrumentation is mainly directed to the creation of smear free canalar surfaces. Glyde File Prep contains EDTA. Because of its acidity, no matter how EDTA is used as irrigant, it needs a last flush with hypochlorite in order to neutralize its acid effect. The technique used for teeth in Group D probably lets EDTA act in the deepest part of the canal, and this may explain why in the apical portion the best results were obtained by this Group.

Other substances have been used to remove the smear-layer, such as 20% polyacrylic acid, 10% citric acid, ortophosphoric and maleic acid (Goldman et al 1981, Wayman et al 1979, Takeda et al 1999). However this acid substances are clinically not easy to handle, as the effect varies according to the kind of acid used,
the concentration and the time of application; besides the low pH (1.5) could have a harmful effect on the periapical tissues (Takeda et al 1999, Garberoglio et al 1994). As alternative to irrigant solutions, Laser (CO₂ and Er:YAG) has also been successfully proposed to remove the smear-layer; however further studies are needed about the thermal effects before the clinical use of lasers can be recommended (Takeda et al 1999).

In conclusion, none of the techniques used in this study showed a perfect removal of smear layer and debris. The significantly lower debris and smear layer scores in Group C and D is probably due to the better effect, as irrigant, of Glyde File Prep combined with sodium hypochlorite 2.5%.

The null hypothesis tested in this study was not confirmed: differences in the amount of debris along root canal walls after different irrigation regimes were noted.
Fig. 1: Composite picture showing a horizontal examination strip at the coronal level of a Group A sample.

Fig. 2: Tooth irrigated with physiological solution (Group A, apical portion) (x 500). An amorphous layer with debris can be noted on the canal wall. No tubule openings are visible.

Fig. 3: Tooth irrigated with NaOCl (Group B, apical portion) (x 500). Smear layer can be noted, with less amount of debris than in Fig. 2. No openings of dental tubule are visible.
Fig. 4: Tooth irrigated with NaOCl and Glyde File Prep (Group C, apical portion) (x 500). Smear layer is not present. The openings of tubule orifices are visible.

Fig. 5: Tooth irrigated with NaOCl and Glyde File Prep applied at the end of the preparation (Group D, apical portion) (x 500). No smear layer is present. The tubule orifices are visible.
References


Chapter 4 Criteria for selecting fiber posts

Actually many fiber posts are available on the market. Their huge success among clinician brought many manufacturers to produce their own fiber post. For this reason it is important for the clinician to know the properties of each fiber post available on the market, and to consequently select the more appropriate. Composition and shape of the post are usually the first criteria. Carbon, glass or quartz fibers are available, and after the first double cylinder shape endodontic and double tapered shape became available. Depending on the type of root canal and of tooth the clinician can decide which one can be more appropriate. Also the combination with an appropriate bonding system acquires high importance: it is known that materials give better results if they are employed following manufacturer’s instructions and if proprietary resin cement and adhesives are used (Ferrari et al 2002). Also the cost can be a factor: some of the posts available on the market are cheaper than others, but we have to keep in mind that a cost/benefit ratio should be taken into account when deciding what kind of material we should employ (Monticelli et al 2003). Probably the most important factor to take into account is the experimental and clinical evaluation of the behaviour of fiber post/adhesive material/resin cement/core material used (Monticelli et al 2003, Ferrari et al 2002, Vichi et al 2001 and 2002). The following study regards a comparison among some post actually available on the market when resistance to fatigue is considered.

4.1 Fatigue resistance and structural characteristics of fiber posts: three-point bending test and SEM evaluation.

Over the recent years a rapid development has occurred in the area of fiber posts. The introduction of carbon fiber posts in 1990 (Duret et al 1990) provided the dental profession with the first true alternative to cast or prefabricated metal posts. The elastic moduli of fiber posts are closer to dentin than that of any metal post (Asmussen et al 1999), and their clinical trials yielded convincing results (Fredriksson et al 1998, Ferrari et al 2000b, Ferrari et al 2000a, Malferrari et al 2002, Scotti et al 2002, Dallari et al 1998). However, the earlier generations of fiber posts had some limitations to their universal use, as they were radiolucent and
difficult to mask under all-ceramic or composite restorations (Vichi et al 2000). Later, radiopaque fiber posts, and more esthetic posts were made. These improvements brought about a drastic change in the acceptance of fiber posts by the dental profession. As a consequence of practitioners finding esthetic fiber posts a viable alternative to metal posts (Drummond et al 1999), a number of different fiber posts were quickly introduced into the market. Many studies are available on the adhesion of fiber posts to root canal substrates (Nakabayashi et al 1998, Chappel et al 1994, Mjor et al 1996), on the different luting procedures (Ferrari et al 2000c, Vichi et al 2002) and the abutment build-up (Gateau et al 1999, Cohen et al 1996, Freedman et al 2001), and all of them demonstrate the quality performances of fiber posts (Dietschi et al 1996 and 1997). The rapid influx of these new esthetic fiber posts has imposed the need for a systematic evaluation of their mechanical properties and clinical performances. For that purpose, scanning electron microscopy (SEM) and fatigue test can provide an indication of what type of post would perform better under clinical conditions. Also, SEM observations can be useful to assess the fiber/resin matrix ratio, as well as the fiber diameter and the global integrity of the posts. Fatigue is considered as one of the main causes of structural failure in restorative dentistry (Hsu et al 2002, Baran et al 2001, Fan et al 1995, Yamamoto et al 1995). It has been reported that dental restorations fail much more frequently under cyclic loading that are well below the ultimate flexural strength of these materials, than under application of a single, relatively high force (Kahn et al 1996). Fatigue tests can reveal the resistance level of each type of post under cyclic loading that simulates the normal occlusal and masticatory function (Gateau et al 1999, Cohen et al 1997, Reagan et al 1999). Since fiber posts are in essence composite materials, it seems logical to expect that their mechanical properties would increase as a result of an increase in fiber content. The objectives of the present study were to assess the fatigue resistance of different types of fiber posts, and to verify the existence of a correlation between the fatigue resistance exhibited by the different types of posts and their structural characteristics. The null hypotheses tested were: 1. there is no difference in the structural characteristics and in the fiber/resin ratio of the posts, 2. there is no difference in the fatigue resistance among different kinds of fiber posts.
4.2 Materials and Methods

Eight types of esthetic posts were selected for this study (Table I).

Table I. This table shows the structural characteristics of the eight groups of tested posts

<table>
<thead>
<tr>
<th>Group number</th>
<th>Type of post</th>
<th>Post diameter (mm)</th>
<th>Fiber diameter (µm)</th>
<th>Fiber density (number of fibers per mm²)</th>
<th>Surface occupied by fibers per mm² of post surface (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>Easypost</td>
<td>1.6</td>
<td>12</td>
<td>29</td>
<td>34.8</td>
</tr>
<tr>
<td>Group 2</td>
<td>Para Post Fiber White</td>
<td>1.5</td>
<td>6</td>
<td>18</td>
<td>10.8</td>
</tr>
<tr>
<td>Group 3</td>
<td>FibreKor</td>
<td>1.5</td>
<td>18</td>
<td>28</td>
<td>30.4</td>
</tr>
<tr>
<td>Group 4</td>
<td>Ghimas White</td>
<td>1.8</td>
<td>12</td>
<td>30</td>
<td>30.0</td>
</tr>
<tr>
<td>Group 5</td>
<td>DT Light-post radiopaque</td>
<td>2.0</td>
<td>12</td>
<td>32</td>
<td>38.4</td>
</tr>
<tr>
<td>Group 6</td>
<td>FRC Postec</td>
<td>2.0</td>
<td>12</td>
<td>25</td>
<td>30.0</td>
</tr>
<tr>
<td>Group 7</td>
<td>Luscent Anchors</td>
<td>1.7</td>
<td>15</td>
<td>29</td>
<td>43.5</td>
</tr>
<tr>
<td>Group 8</td>
<td>Snowpost</td>
<td>1.6</td>
<td>7</td>
<td>36</td>
<td>25.2</td>
</tr>
</tbody>
</table>

They were Easypost (Krugg, Milano, Italy; Group 1, carbon fibers), Para Post Fiber White (Coltene/Whaledent, Mawhaw, NJ, USA; Group 2, glass fibers), FibreKor (Jeneric/Pentron, Wallingsford, CT, USA; Group 3, glass fibers), Ghimas White (Ghimas, Casalecchio di Reno, Bologna, Italy; Group 4, glass fibers), DT Light-Post radiopaque (RTD, Grenoble, France; Group 5, pre-tensioned glass fibers), FRC Postec (Ivoclar-Vivadent, Schaan, Liechtenstein; Group 6, glass fibers), Luscent Anchors (Dentatus, New York, NY, USA; Group 7, glass fibers), Snowpost (Carbotech, Ganges, France, Group 8, silica fibers). From each group fifteen posts of the largest available size (Table I) were collected. The size of the post in the different groups varied from 1.5 mm to 2.0 mm. Ten of them, randomly chosen, were used for fatigue test, whereas the other five were processed for microscopic evaluation.

4.2.1 Fatigue test

Ten posts from each group were tested in a fatigue machine (Procyon systemes, France). This device has a counter that measures the number of cycles and stops when the specimen breaks (Fig. 1). The three-point bending method of loading was
applied, with a loading angle of 90° at a frequency of 3Hz. As the posts in the eight groups had different diameters, a calculation was done to establish the load to be applied on the different posts, according to the diameter itself.

\[ \delta = \frac{8 \times F \times I}{\pi \times d^3} \]

\[ \delta = \text{stress (N/mm}^2 = \text{MPa)} \]

\[ F = \text{load or force (Newton)} \]

\[ I = \text{span (mm)} \]

\[ d = \text{diameter (mm)} \]

The load was applied according to the diameter of post

\[ F = \frac{\delta \times \pi \times d^3}{8 \times I} \]

The two supports and the punch had a 3-mm diameter, and the distance between the two supports was 9 mm. All the tests were carried out at a room temperature of approximately 22°C. The machine was set to carry out 2,000,000 cycles, the assumption being that, as teeth normally come into contact once a minute, this number of cycles would simulate about four years of physiologic occlusal and masticatory activity (Ferrari et al 2000b, Scotti et al 2002).

For those fiber posts that failed prior to reaching the projected cycle count, the actual number of resisted cycles as counted by the fatigue machine was recorded. The differences among the tested posts in the number of resisted cycles were tested for statistical significance with the One-Way ANOVA, followed by the Bonferroni test for multiple comparisons. The level of significance was set at p<0.05.

At the completion of the fatigue test, the posts were processed for a SEM evaluation, which was aimed at verifying whether any changes had occurred in the structure of the post as a result of loading. The detected modifications were documented through microphotographs.

4.2.2 SEM evaluation

Each post was cross-sectioned into two halves using a diamond saw (Isomet, Buehler, Lake Bluff, NY). One half was used for the observation of the surface
exposed by the cross-sectional cut, whereas the other half was again sectioned longitudinally (with the same diamond saw described above), in order to examine the fibers along their longitudinal axes. The external surface of this half of each sectioned fiber post was also examined. The specimens were mounted on metallic stubs, and sputtered with gold in an ion-sputtering device (Balzers Ltd., London, Great Britain). Then the specimens were analyzed under a scanning electron microscope (Philips 505, Eindhoven, The Netherlands), and microphotographs were taken for documenting the morphologic characteristics of posts. The diameter of the fibers, the number of fibers per mm$^2$, and the surface occupied by fibers per square millimeter of post surface were measured. Three micrographs were taken for evaluating each post, and the result was obtained calculating the mean of the score assigned to the three single micrographs. Also, the presence of voids/bubbles within the post and on its outer surface was assessed and expressed through a three-step scoring system, which was defined as: 0 = no voids or bubbles visible; 1 = micro voids or bubbles can be detected (diameter < 20 microns); 2 = voids or bubbles (diameter > 20 microns) are evident and/or fiber detachments due to a loose bond within the resin matrix. The scoring method allowed for a quantitative evaluation of the structural integrity of the posts, as well as for a statistical evaluation of the differences among the various types of post. SEM scores were assigned by two different operators, who separately examined the micrographs taken from the specimens. In case of disagreement between the two investigators on the score assigned to a specimen, the worse score was chosen for the statistical analysis. The observations were repeated twice to verify the inter-examiner reliability. The differences in the scores recorded for the eight groups of posts were tested for statistical significance with the Kruskal Wallis ANOVA on ranks, followed by the Mann-Whitney U test for multiple comparisons. The level of statistical significance was set at $p<0.05$.

**4.2.3 Correlation analyses**

A further objective of the investigation was to verify the existence of a correlation between the fatigue resistance exhibited by the different types of posts and their structural characteristics, namely fiber diameter, fiber density, and the surface occupied by fibers per square millimetre of post surface. For that purpose, the
strength of the correlation between the number of resisted cycles and each one of the mentioned structural variables of the posts was measured by calculating the Pearson’s correlation coefficients. The statistical significance of the correlations was also assessed (p<0.05).

4.3. Results

4.3.1 Fatigue tests

Table II reports the means and standard deviations of the number of cycles that the different types of posts were able to withstand before breaking.

Table II. Mean and standard deviation of the number of cycles that each type of post proved able to withstand before breaking.

<table>
<thead>
<tr>
<th>Group number</th>
<th>Type of post</th>
<th>Mean number of resisted cycles</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>Easypost</td>
<td>931750.2</td>
<td>82905.8</td>
</tr>
<tr>
<td>Group 2</td>
<td>Para Post Fiber White</td>
<td>84915.7</td>
<td>106039.0</td>
</tr>
<tr>
<td>Group 3</td>
<td>FibreKor</td>
<td>29687.8</td>
<td>24372.5</td>
</tr>
<tr>
<td>Group 4</td>
<td>Ghimas White</td>
<td>440952.9</td>
<td>160671.8</td>
</tr>
<tr>
<td>Group 5</td>
<td>DT Light-post radiopaque</td>
<td>2000000.0</td>
<td>0</td>
</tr>
<tr>
<td>Group 6</td>
<td>FRC Postec</td>
<td>1837138.7</td>
<td>371387</td>
</tr>
<tr>
<td>Group 7</td>
<td>Luscent Anchors</td>
<td>807242.9</td>
<td>2008</td>
</tr>
<tr>
<td>Group 8</td>
<td>Snowpost</td>
<td>6763.1</td>
<td>780</td>
</tr>
</tbody>
</table>

The results of the statistical analysis performed on these data are summarized in Figure 2.

The highest resistance to cyclic loads was exhibited by the DT Light-post group (Group 5), followed by the FRC Postec group (Group 6). None of the specimens from the DT Light-Post group was broken after two million cycles, whereas among the FRC Postec posts only one failure occurred. From a statistical standpoint the results given by these two groups were similar (Fig. 2). Conversely, Snowpost, FibreKor, and Para Post (Groups 8, 3, and 2) showed fatigue resistance that were significantly lower than that of any other post tested (Fig. 2).

4.3.2 Structural integrity

The scores assigned to the different types of posts in order to quantify their structural integrity, as revealed by SEM observations, are summarized in Table III.
Table III. Median values of the scores assigned to the different types of posts, providing an estimate of posts’ structural integrity, as shown by scanning electron microscopy.

<table>
<thead>
<tr>
<th>Group number</th>
<th>Type of post</th>
<th>Scores</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Cross section of the post</td>
<td>Longitudinal section of the post</td>
<td>External surface of the post</td>
<td></td>
</tr>
<tr>
<td>Group 1</td>
<td>Easypost</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Group 2</td>
<td>Para Post Fiber White</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Group 3</td>
<td>FibreKor</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Group 4</td>
<td>Ghimas White</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Group 5</td>
<td>DT Light-post radiopaque</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Group 6</td>
<td>FRC Postec</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Group 7</td>
<td>Luscent Anchors</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Group 8</td>
<td>Snowpost</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

The specimens from the Easypost, Para Post, and Luscent groups (Groups 1, 2, and 7) exhibited voids and/or bubbles within the post structure on both the cross and the longitudinal sections. The specimens from the Easypost group (Group 1) also showed gaps between the fibers and the resin matrix, in particular in the peripheral area and on the external surface of the post. The Easypost and Para Post groups recorded scores that were significantly higher than those of any other type of post (p<0.05; Fig. 3). Only on the specimens from DT Light-post (Group 5), FRC Postec (Group 6), and Ghimas White (Group 4) were no structural defects visible either on the cross and longitudinal sections or on the outer surface of the post. The scores assigned to these three types of posts were significantly lower than those of any other group (p<0.05; Fig. 3).

When the posts that were fractured after load cycling were observed under the SEM, their loss of structural integrity was evident (Fig 4). On the other hand, the DT Light-post and the FRC Postec posts, which were able to withstand the fatigue test, exhibited only a small circumferential depression in the area of contact of the loading punch (Fig 5).
4.3.3 Correlation analyses

The data expressing the strength of the correlation between fatigue resistance and structural characteristics of the posts are summarized in Table IV. No correlation was found to be statistically significant (p>0.05).

Table IV. Strength and statistical significance of the correlation between fatigue resistance of the posts and their structural characteristics.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Fibers diameter</th>
<th>Fibers density</th>
<th>Surface occupied by fibers per square millimeter of post surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pearson’s correlation coefficient</td>
<td>r = 0.167</td>
<td>r = 0.069</td>
<td>r = 0.171</td>
</tr>
<tr>
<td>Statistical significance</td>
<td>p = 0.693</td>
<td>p = 0.871</td>
<td>p = 0.685</td>
</tr>
</tbody>
</table>

4.4 Discussion

As fiber-reinforced composite materials, fiber posts owe their mechanical properties not only to the characteristics of fibers and matrix, but also to the strength of the bond at the interface between these components and to the geometry of reinforcement, such as fiber length, orientation and concentration (Callister et al 1997). The addition of fibers to a polymer matrix leads to a significant increment in fracture toughness, stiffness, and fatigue resistance of the material. Since fibers represent the stiffer component in a post, as compared with the resin matrix, the posts that exhibit a higher fiber density (Figure 4) would be expected to yield a greater fracture resistance than those with lower fiber densities (Figure 5) (Callister et al 1997). Any fiber direction diverging from the longitudinal axis of the post results in a stress transmission to the matrix. For this reason, posts with parallel fibers should, at least theoretically, withstand loads more efficiently than posts containing obliquely-oriented fibers (Callister et al 1997).

In the fabrication of endodontic posts, glass, quartz, carbon, and ceramic fibers have been used (Drummond et al 1999, Asmussen et al 1999). The posts produced by RTD and Ivoclar-Vivadent contain silanized glass fibers and an epoxy resin. During
the manufacturing process of RTD posts, the fibers are pre-stressed in tension and then soaked in resin, which is finally polymerized. On the final cure of the resin, the tension in the fibers is released and, as a result, the resin surface is placed under compression. For this reason, when the post is subjected to a flexural force, the tensile stresses which are introduced can easily be absorbed. For the Ivoclar-Vivadent posts, they are made following the Vectris technology (Vichi et al 2001). The methods of fabrication of DT Light-post and FRC Postec can provide an explanation for the significantly higher resistance to fracture under cyclic bending forces. Unfortunately manufacturers do not declare the modulus of elasticity of the resin employed as the resin matrices of these posts: it could eventually play an important role in the determination of the fatigue resistance of the post. Another important factor is whether the fibers are silanized prior to embedding in the resin matrices: in particular, it can affect both the resistance of these fiber posts to the fatigue tests as well as the structural integrity of these posts. Good interfacial bonding ensures load transfer from the matrix to the reinforcement, and is a primary requirement for effective use of reinforcement properties (Gu 1997).

During normal occlusal and masticatory function, both the natural and the restored teeth are subjected to cyclic loading. Thus, failure due to fatigue stress is a phenomenon of paramount importance from a clinical standpoint (Dietschi et al 1996 and 1997, Hsu et al 2002), as failure commences from a small structural defect such as a void or microcrack within the material. From this area of weakness a crack front can gradually propagate through the material, finally resulting in catastrophic failure (Griffith et al 1920). Potential areas of weakness in a fiber-reinforced post can be seen in the voids present within the resin or in the discontinuities along the interfaces between fibers and matrix. Thus, a solid void-free post with evenly distributed and parallel-oriented fibers seems to be critical for their clinical success. Areas of potential weakness may also be found in regions where the section of the post has an abrupt change (Baran et al 2001). For this reason, the addition of a notch on the post for the purpose of retention does not seem to benefit the post’s fatigue resistance. The SEM observation of posts that fractured under load showed how their structure was altered by the fatigue stress.
In the fatigue test, as in a repeated masticatory action, the load varies between a minimum (Kmin) and a maximum (Kmax). Theoretically the moment in which a rapid fracture occurs has to be related to the Kmax value. On the other hand, the difference between the maximum and the minimum values (K) corresponds to the cyclic dissipation of stress energy. The two different values (Kmax and K) combined provide important information, and are likely to be simulating what really happens in the mouth (Wiskott et al 1997).

In the present study a load ranging from 20 to 100 N was applied at a frequency of 3 Hz. With the 20-N force, the loading unit was kept in stable contact with the specimen. In fatigue tests, Kmax does not usually exceed 50% of the ultimate strength of the material (Cohen et al 1996). This criterion was applied also in the present study, and the results showed that specimen failure could occur when a cyclic force as low as one half of the material’s ultimate strength was exerted.

The stress acts on the matrix particularly when a compressive force is exerted on the post or when the forces are directed obliquely or diagonally to the post’s longitudinal axis. The high stresses on the fiber/resin interface are responsible for a gradual inelastic behaviour, which occurs as a consequence of interface detachment between the fibers and the matrix. Also plastic deformation of the matrix and resin microcracking occur. Such stresses are minimum in the equidistant areas of the fibers, and maximum immediately next to the same fibers (Grandini et al 2002a).

Regarding the fracture mode of the post, it is speculated that when failure commences under compression the more brittle fibers break due to variability in individual fiber surface defects. This leads to interfacial slip between the broken fiber and the matrix, and consequently stress magnification in the adjacent fibers. As the interfacial bond is probably still effective, tensile stress in the broken fiber along the bond transfer length will gradually build-up. If the bond strength is exceeded, delamination of the fiber from the matrix will commence and propagate (Grandini et al 2002a). With interfacial bond lost progressive fiber fracture will occur leading to overall catastrophic failure. Further detailed fractographic analysis should be performed to validate the results of this study.

The overall results of this study require rejection of both null hypotheses. Differences exist among different brands of fiber posts in terms of their structural
characteristics and fatigue resistance, although little correlation was observed between these two attributes. DT Light-post and FRC Postec can be expected to function efficiently in their ability to resist fatigue stresses. This factor adds to the reliability of these materials when used clinically for the restoration of endodontically treated teeth.

In conclusion, the overall results of this study require rejection of both null hypotheses. Differences exist among different brands of fiber posts in terms of their structural characteristics and fatigue resistance, although little correlation was observed between these two attributes. Wiskott et al. (1997) indicated that the number of cycles in fatigue testing should be at least one million cycles. In the present study, a maximum of two millions cycles was applied, with the intention of simulating about four years of normal occlusal and masticatory activity (Ferrari et al. 2000b, Scotti et al. 2002). It should be pointed out that the cyclic fatigue test performed in this study most likely exposed the specimens to higher tensile stresses than those that would have actually been transmitted to an endodontic post cemented inside a root, as failure of the bonding cement could have occurred prior to post fracture. For this reason, in order to have a fatigue resistance appraisal that is closer to clinical reality, the same study should be repeated on roots with cemented posts instead of just posts. This requires a completely different study design that does not involve three-point bending test.
Fig. 1. The post ready to be tested.
<table>
<thead>
<tr>
<th>Type of Posts</th>
<th>Mean Number of Cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Para Post, FibreKor, Snowpost vs * (-)Light-post, Postec, Easypost, Luscent Anchors</td>
<td>500000</td>
</tr>
<tr>
<td>Ghimas vs * (-)Light-post, Postec</td>
<td>1000000</td>
</tr>
<tr>
<td>Easypost, Luscent Anchors vs * (-)Light-post, Postec</td>
<td>1500000</td>
</tr>
<tr>
<td>Snowpost, FibreKor, Para Post</td>
<td>2000000</td>
</tr>
<tr>
<td>FRC Postec, DT Light-post vs * Snowpost, FibreKor, Para Post, Ghimas, Luscent, Easypost</td>
<td>2500000</td>
</tr>
</tbody>
</table>

Fig. 2. Graph representing the mean number of cycles that each type of post was able to resist before failing. Columns underlined by the same line represent groups which gave statistically similar results. In the table, the star sign indicates that the difference between the groups was statistically significant. The minus sign indicates that the difference between the two mean values was negative.
Fig. 3 Mean of the ranks that the statistical analysis (Kruskall Wallis test) assigned to the scores of each group of posts. The columns underlined by the same line represent groups of post that recorded statistically similar scores.
Fig. 4 A sample from group 7. The fatigue test caused the breaking of the post.
Fig. 5 Group 5 sample. After 2,000,000 cycles the post is still unbroken. The point where the loading punch worked is evident.
References


Griffith AA. The phenomena of rupture and flow in solids. Philosophical Transactions of the Royal Society of London (Series A) 1920; A221: 168-198.


Chapter 5  Adjusting the length of a post

As the wear properties of fiber posts are inferior if compared to resin composite materials, it is not safe to have them exposed to the tooth to tooth and tooth to food wear. If a crown is placed, the exposed fiber post is protected by the crown itself. If a direct restoration is made, it is convenient to cut the post before the luting procedures of the post itself (Ferrari et al 2002). As a matter of fact fiber posts are pre-fabricated, so they have to be adapted to the root and to the crown length. The following study regards a comparison between different techniques for cutting fiber posts.

5.1 Scanning electron microscopic investigation of the surface of fibre posts after cutting

At the beginning of 1990 carbon fibre posts were proposed as alternative to metallic posts (Duret et al 1990). In the last 10 years, different types of fiber posts were proposed to improve mechanical and esthetic properties of fibre posts (Fredrikson et al 1998, Dallari et al 1998, Ferrari et al 2000a). Initially hybrid posts and almost simultaneously white quartz posts were proposed (Scotti et al 2000, Ferrari et al 2000b). More recently, translucent posts became available. As the development of fibre posts was very quick, all these types of posts are still in the market and are routinely used by practitioners. Recently, clinical efficacy and performances of 3 different types of fibre posts were documented (Fredrikson et al 1998, Dallari et al 1998, Ferrari et al 2000a, Scotti et al 2000, Ferrari et al 2000b). All different types of fibre posts have a similar strength and stiffness (Asmussen et al 1999). The stiffness (or modulus of elasticity) of the posts is similar to that of dentin and, for that, the risk of root fracture became much lower than that noted when metallic posts were used (Ferrari et al 2000a). In addition, bonding between different types of posts and resin cements has been demonstrated (Mannocci et al 1999, Ferrari et al 2001, Vichi et al 2002).

Fibre posts are made in a standardised length in order to be adapted to the length of different roots. Each post must be tried in and then cut at the most convenient length in order to avoid exposition of the post along the surface of the abutment/restoration.
This is due to the fact that the exposition of the post in to the oral environment might determine degradation of the resin with a consequent loss of its mechanical properties during clinical service. However, in order to have a sufficient rigidity of the abutment at the coronal level, the post must keep its integrity and mechanical properties after being cut.


The aim of this study was to evaluate 1. if and how three cutting methods can affect integrity of fibre posts and 2. to test the null hypothesis that the type of cutting procedure can not affect the integrity of post’s surface.

5.2 Materials and Methods

Among those available in the market, six types of fibre posts were selected for this study: Caron Fibre Posts (RTD, St Egreve, France) as control, Quartz Fibre Posts (RTD), Aesthetic Posts (RTD), Aesthetic Plus Posts (RTD), Translucent Posts (Dentatus, Zurich, Switzerland), FRC Postec Posts (Ivoclar-Vivadent, Schaan, Liechtenstein). Fifteen posts of each type were used. A total of 90 posts were evaluated.

All fiber posts had a diameter between 1.2 and 1.4 mm and a standardised length (between 14-16 mm). Each group was divided into three subgroups, according to the cutting method: a. Diamond bur, b. Carborundum disk and c. Scissors (Fig 1).

5.2.1 Subgroup a (diamond bur): Five samples of all six groups were cut approximately between medium and coronal third using a diamond bur (2979, Komet, Zurich, Switzerland) mounted in a turbine handpiece under water spray. Both sections of each sample were collected and then mounted in a metallic stub to observe the cut surfaces. Then, the samples were gold-coated (Edwards Co, London, GB), evaluated using a scanning electron microscope (Philips 515, Amsterdam, The Netherlands) and microphotographs were taken at different magnifications (x36, 200, 500, 1010) in order to properly document their cut surfaces.

5.2.2 Subgroup b (carborundum disc): Other five samples of each group were used. The posts were cut using a carborundum disk mounted in a handpiece (L.I.M.A.,
Torino, Italy). Then the samples were processed microscopically (for SEM observations) as described for Subgroup a.

5.2.3 Subgroup c (scissors): The last five samples of each group were cut using scissors (Dentronix Inc., New York, NY, USA). Then, both halves of each post were processed as described above for subgroup a and b.

5.3 Results
Analysis of the fibre posts after being cut showed different features mainly due to the cutting procedures. Uniform results were found according to the type of cutting procedure.
At low magnifications, no microscopic differences were found among the samples of group 1-4 and 6. Only samples of group 5 showed more irregular surfaces after being cut with the two procedures providing rotary instruments (subgroup a and b). All groups showed evident differences between cut surface of subgroup c samples and those of group a and b.
In subgroup a, posts showed regular surfaces after cutting with diamond bur (Fig. 2). Cutting with a carborundum disc (subgroup b) brought to an almost regular surface, but in all groups with some burs and sometime ‘burns’ close to the surface borders.
In subgroup c, in which the posts were cut using scissors, the cut surfaces of all samples showed two plane and convergent flanges (Fig. 3); also due to formation of fracture lines, these posts loose their integrity not only at the cutting surface but also along their length.
At higher magnifications, the structure of all type of posts, based on fibres embedded in a resin matrix, was observed. Also, in subgroup a and b samples the cutting procedure produced a smear layer mainly covering the cut post surface.

5.4 Discussion
Cutting fibre post procedure is commonly performed before luting procedures or/and during build-up and final preparation of the abutment. During this clinical step, a good adaptation of the post at the coronal third of the root canal preparation and a proper adhesion to the resin cement and composite material used for build up of the tooth at the coronal level is desirable.
The findings of this study revealed significant differences in post surfaces after cutting, similarly to those already described for gutta-percha cones (Lopes et al 2000).

The loss of integrity of the posts noted after having been cut with scissors might negatively affect the adaptation of the post to apical and medium thirds of the root preparation and to the resin composite used for the coronal build-up. Also, the loss of integrity of the posts after cutting using scissors can probably reduce their mechanical properties (Fig 4).

In Subgroup a, samples of groups 1-4 and 6 showed regular cut surfaces. The cut using diamond bur creates shear stress in the cross-section of the post, but the speed of the handpiece reduces the plastic deformation of the post. Therefore the stress tensions induced by the diamond bur allow the development of an almost plane cut surface, which is perpendicular to the direction of displacement of the cut instrument. In Subgroup b, posts of groups 1-4 and 6 also showed a regular cut surfaces. The tips of the posts were irregular and some burs were observed close to the surface boarders. These probably occurred because the posts were not cut against a surface, which could create a mechanical resistance load opposed to the cut direction. In Group 5 a less regular cut surface was noted for the two procedures based on high speed cutting (subgroup a and b). This can be due to the different stiffness of the posts and their fibre disposition. As a matter of fact, in group 5 samples, the density of the fibres might be less uniform than that of the other groups and this fact can determine a different plasticity of the post and consequently the irregular cut. When subgroup a and b were compared, a more regular cut surface was observed in subgroup a. This difference might be due to the fact that water cooling was only used in combination with turbine handpiece, and also to the higher speed of this cutting procedure. In Subgroup c, in which the posts were cut using scissors, the cut surfaces of the samples of all groups showed two plane and convergent flangers. The magnitude of the post deformation after cutting depends on both scissors shape and post plasticity. Also, the posts showed an area of cut surfaces where fibres were irregularly cut at different lengths and a deattachment between fibres and resin matrix was evident along their length.
Fig. 12 shows the kind of loading applied on the post during cutting with scissors. At point P and P’, plastic deformation of the posts occurs. As the load increases, the post is moved through the two blade surfaces of the scissors, producing two different inclined planes. Other studies have reported similar results when gutta-percha cones were cut (Lopes et al. 2000).

However, every time a fibre post is cut, the cut of the post occurs by the application of a shear stress in the transverse section of the post. The cutting procedure induces an elastic compression/deformation of the material. Close to the cut surface, post fibres bend in a direction that is similar to the movement applied by the cutting instrument. When the applied pressure overcomes the elastic resistance of the material, the fibre post is separated.

As the cutting with the carborundum disk (subgroup b) might be associated with irregularities in the cut post surface, a second cut might be desirable to repair the defects. Thus, whereas the first cut allowed the calibration of the post, the second cut can regularise the post surface (Fig 5).

Probably the speed of bur/disc mounted on the handpiece played a role such as also the stiffness of the posts. It may happen that a “burn out” phenomenon takes place if excessive heating is applied (Fig 6). The posts of group 1-4 are made by the same company following the same procedure: for that the similar behaviour during cutting posts of Group 1-4 can be related to their structure and stiffness. Posts of group 6 have similar stiffness (modulus of elasticity) than that of RTD posts (group 1-4) and because of that they might show similar cut surface.

Also, when different posts have similar stiffness, the speed of the bur/disc played a key role in subgroups a and b to obtain better results.

Cutting procedures can have clinical implications. After the coronal build-up, the abutment can be prepared in order to finalise its shape to receive a crown or to refine the anatomy of the coronal portion of the tooth. In these clinical steps the quality of bonding between the post and the resin composite used for building it up is critical: it must be without discontinuity between the two portions and the length of the post at the coronal level must be sufficient to hold occlusal stress. If the post presents a superficial and internal loss of its integrity due to the cutting procedure, the bonding between the post and the resin composite is less uniform, discontinuity might be
easily present in between, and the possibility of a fracture of the abutment highly increases.

The cutting procedure using scissors must be avoided. It must be considered that cutting the post is usually performed after trying-in into the root canal space and before luting it. If the cutting procedure is performed at this clinical step, the rotary cutting procedures tested in subgroups a and b might be used. If the cutting procedure is performed after luting the post, it is strongly suggested to reduce the length of the post with a diamond bur (as tested in subgroup a) after building-up the abutment and during its final preparation.

The results of this study indicated that fibre posts can be regularly cut off using a diamond bur mounted in a handpiece under copious water cooling. Although carborundum disc cutting procedure (subgroup b) showed a less regular post surface, it can be speculated that it might be clinically acceptable. The results of this study might be extrapolated to other fibre posts with similar properties already available in the market.

The null hypothesis tested in this study was not confirmed, because post surface morphology was related to the type of cutting procedure.
Fig. 1: Fibre posts were cut with diamond bur, carborundum disc or scissors.

Fig. 2: Cutting procedure with diamond bur often created a flat and regular surface (x 36).
Fig. 3: Cutting procedure with scissors. Two planes and convergent flanges are visible (x 36). Loss of integrity and morphology of the post is clearly noted.

Fig. 4: Cutting procedure with scissors. The loss of integrity is clearly visible (x 25).
Fig. 5: A second cut can help making more regular the cut end (x 36)

Fig. 6: Excessive heating of the post (x 36)
References


Scotti R. Ricostruzioni preprotesiche con perni in fibra di quarzo: esperienza clinica a 18 mesi. Odontoiatria adesiva e ricostruttiva, S. Margherita Ligure, 2000; 21-27.

Chapter 6  Selection of clinical luting procedures

When fiber posts are employed proper luting is a prerequisite. Depending on what type of fibers are involved, different options can be taken into account. The first step is the removal of the guttapercha and the preparation of the dowel space, usually enlarged with a low-speed bur provided by the manufacturer. The depth of the post space preparation is around 9-10 mm. Then the post has to be tried into the canal, so to avoid imperfect fitting and excess of cement at the tip end of the post; if this happens the post cannot be seated in the correct position. The root canal walls are etched with phosphoric acid (usually 37%) for 15 (or 30) seconds, washed with water spray and then gently air-dried. The excess water is removed from the post space using paper points. Subsequently, adhesive is applied with a microbrush, gently air-dried and the pooled adhesive left in the post space removed using a paper point before light curing for 20 seconds. Then a dual-cure resin cement (for translucent posts) or a self-curing resin cement (for non-translucent posts) is used to complete the luting procedure. According to the diameter and the shape of the canal, different brands and sizes can be utilized. The cement is applied with a lentulo spiral into the post space, and the post inserted into the canal. Resin cement excess is removed with a clean microbrush and then the cement light-cured for 40 seconds (Monticelli et al 2003, Vichi et al 2002a and 2002b, Ferrari et al 2002). Some clinicians suggest to use the same material for the cementation of the post and the build up of the abutment: it is actually difficult to obtain a material that is hard enough to be used as a core and that at the same time can flow in the canal like a cement. Recently new simplified materials appeared on the market (RelyX Unicem, 3M Espe, St Paul, MN, USA) that have also been proposed for bonding fiber posts into root canals. The bonding mechanism of this self–adhesive resin cement is still debated, but it has been recently proven that if the substrate is non etched dentin and if a certain pressure is applied during the luting procedures (the situation we find in the root canal) there are encouraging results (De Munck et al 2004).

In this chapter an alternative to the well established procedure described above is discussed.
6.1 A one step procedure for luting glass fibre posts: an SEM evaluation

The potential of fibre reinforced materials in restorative dentistry has been appreciated for some time (Bradley et al. 1980). However, the concept of carbon fibre posts as a method for reconstructing root filled teeth was not described until later (Duret et al. 1990). Subsequent research confirmed the retention potential of carbon fibre posts (Drummond et al. 1999, Asmussen et al. 1999), the low stressing behaviour of the fibre post-resin cement complex, and its good clinical performance (Fredrikson et al. 1998, Ferrari et al. 2000a, Malferrari et al. 2002, Scotti et al. 2002).

Various changes have been made to fibre post composition, radiopacity, and shape (Love & Purton 1996, Asmussen et al. 1999, Vichi et al. 2002a). For example, carbon has been replaced by quartz in the fibre composition, and then by glass. The manufacturers have recently developed posts that are radiopaque, allowing the clinician them to be seen on radiography. Several modifications have been made to post configuration, with the aim of achieving better adaptation to root canal shape. It is possible to transmit light through a glass fibre post that is translucent. Light transmission through the post might permit a bonding procedure, in combination with an acid-etching technique, based on a light curing adhesive system (as for the other posts) and a dual curing resin cement (Vichi et al. 2002a). The translucent fibre post has a modulus of elasticity similar to that of the other fibre posts and of dentin, and offers adequate mechanical properties (Dietschi et al. 1997, Asmussen et al. 1999). Transmission of light through the post also makes it possible to light-cure the resin cement and the bonding system in only one clinical step (“one-shot”), thus simplifying and shortening the clinical procedure (Lui 1994).

Evaluation of the efficacy of an adhesive system can be performed by observing the uniformity of the resin dentin interdiffusion zone (RDIZ), resin tags, and adhesive lateral branches (Nakabayashi & Pashley 1998), and by recording the presence of voids/bubbles within the luting material or at the interface between the cavity wall and the post (Ferrari et al. 2001a). An evaluation of the quality of the RDIZ is not possible using scanning electron microscopy (SEM), rather TEM is the appropriate way to assess it (Tay et al. 1995).
Recently, the so called ‘one bottle’ adhesive systems have been proposed for bonding a fibre post into a root canal (Ferrari et al. 2001b). In order to perform reproducible studies and to apply a statistical analysis, a method for scoring resin tags, adhesive lateral branches, and RDIZ into root canal etched dentin has been proposed (Ferrari et al. 2001a).

The aim of this study was to evaluate the efficacy of a one-step technique (“one-shot”) in forming resin tags, adhesive lateral branches and RDIZ when luting translucent fibre posts into root canal preparations. The null hypothesis that the one-step technique creates the same bonding mechanism into root canal dentin than the more traditional two-step luting procedure was tested.

6.2 Materials and Methods

Forty mandibular anterior teeth (incisors and canines), stored in a 0.1% thymol solution, were randomly selected for the study from the department’s stock of extracted teeth. Canal morphology was verified from radiographs (Kodak, Rochester, NY, USA) (70 KV and 0.08 s), taken both buccolingually and mesiodistally. The pulp chambers were opened and canal preparation at a working length 1 mm from the apex was completed to a 35 size master apical file. A step-back technique was used with stainless-steel K-files (Union Broach, New York, NY, USA), Gates Glidden drills size 2 to 4 (Union Broach). Irrigation was performed using 2.5% sodium hypochlorite and EDTA (Glyde File Prep, Dentsply Maillefer, Ballaigues, Switzerland). The prepared teeth were obturated with thermoplasticized, injectable gutta-percha (Obtura, Texceed Corp., Costa Mesa, CA, USA), and resin sealer (AH-26, DeTrey, Zurich, Switzerland).

The root canal walls of each sample were enlarged and the gutta-percha removed with the low-speed drills provided by the manufacturer (RTD, St. Egrève, France), to a depth of 9 mm from the cementum-enamel junction. The samples were randomly divided into four groups of ten specimens each (Table 1).
Table 1: Bonding-luting procedures

<table>
<thead>
<tr>
<th>Group</th>
<th>Bonding system</th>
<th>Clinical steps</th>
<th>Resin cement</th>
<th>Clinical steps</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>OS</td>
<td>a,b,c</td>
<td>Duo-Link</td>
<td>d,e,f,g,h</td>
</tr>
<tr>
<td>2.</td>
<td>OS - 30</td>
<td>a,b</td>
<td>Duo-Link</td>
<td>d,e,f,g,h</td>
</tr>
<tr>
<td>3.</td>
<td>OS - 60</td>
<td>a,b</td>
<td>Duo-Link</td>
<td>d,e,f,g,h</td>
</tr>
<tr>
<td>4.</td>
<td>OS – 90</td>
<td>a,b</td>
<td>Duo-Link</td>
<td>d,e,f,g,h</td>
</tr>
</tbody>
</table>

- a. Dentin conditioning with phosphoric acid
- b. Primer application with microbrush
- c. Light-curing
- d. Post treated with the Primer-adhesive solution
- e. Mixing resin cement
- f. Cement application into the root canal with a lentulo drill
- g. Removing resin excess
- h. Light-curing through the translucent fibre post

OS: One-Step (Bisco, Schaumburg, IL); Duo-Link (Bisco)

Group 1: The first ten specimens were treated with One Step bonding system (Bisco, Schaumburg, IL, USA), following the manufacturer’s instructions (Ferrari et al 2000b). The root canal walls were etched with 32% phosphoric acid (Bisco) for 15 s, washed with water by means of a syringe with a small endodontic needle, in order to completely remove the acid, and then gently air-dried. Excess water was removed from the post space using paper points. Four coats of primer-adhesive material were placed in the root canals with a thin microbrush Plus (Microbrush Co., Greyton, WI, USA) (Ferrari et al 2001b). The excess primer-adhesive solution was removed with a paper point, gently air-dried, and then cured by applying the light tip at the canal orifice, parallel to the long axis of the root for 20 s. For curing purposes, a VIP curing device (Bisco) was used, with a light intensity of 600 mW/cm². Duo-Link (Bisco) resin cement, a dual cure resin cement, catalyst and base were mixed and used following the manufacturer’s instructions. The resin cement was applied into
the root canal space with a lentulo drill, the fibre post was seated, and the excess resin removed and each specimen light-cured for 20 s through the post.

Group 2: Ten root specimens were treated as Group 1 samples. The only difference was that the primer/adhesive solution One Step (Bisco) was not cured immediately. Rather, the dual-cure resin cement was applied with a lentulo drill, the post was placed in the root canal preparation, and only at this time were the adhesive material and the cement light-cured simultaneously through the post for 30 s.

Group 3: These roots were treated as described in Group 2. The simultaneous light-curing was performed for 60 s.

Group 4: These samples were treated as described in Group 2. The simultaneous light-curing was performed for 90 s.

DT light posts (RTD, St Égrève, France) were used in the 40 samples (Boudrias et al. 2001). Depending on the size and the shape of the root specimens, number 1 (tip diameter = 90, taper 06) and 2 (tip diameter = 100, taper 08) DT posts were used. The length of each post was controlled before the luting procedure, and the post was sectioned to match the length to the root canal preparation.

After complete setting of the cement, crown build-ups were performed with the proprietary resin composite (Biscore, Bisco) to eliminate the chance of incompatibility between the luting cement and the core material.

The teeth were stored in water at room temperature for 1 week. The roots were then sectioned parallel to the long axis of the tooth using a diamond saw (Isomet, Buehler, Lake Bluff, NY, USA), at slow speed under water.

6.2.1 RDIZ observations

One section of each root was gently decalcified (32% phosphoric acid was applied for 30 s; the sample was then washed and gently air-dried) and deproteinized (the sample was immersed in a 2% sodium hypochlorite solution for 120 s), in order to evaluate RDIZ formation.

After being extensively rinsed with water, the specimens were gently air-dried and dehydrated with alcohol, sputter-coated with gold (Edwards Ltd, London, UK) and observed under a scanning electron microscope (Philips 515, Philips Co., Amsterdam, The Netherlands) at x1010 magnification. The observations were made.
by two operators, and repeated twice in order to ensure intra examiner consistency. When a different score was given, the lower score was taken into account.

The following aspects were evaluated by scanning electron microscope:

1. The continuity of the RDIZ: this variable was assessed as the percentage ratio between the length of the RDIZ and the total length of the adhesive interface using a visual and computer aided examination and calculation. The differences among the average ratios calculated for the four groups were tested for statistical significance. The One-Way ANOVA and Newman-Keuls Multiple Comparisons Test were applied, setting the level of significance at p=0.05.

2. The presence or absence of gaps: a. Inside the adhesive layer, b. Between the adhesive and the resin cement layer, c. Inside the resin cement layer, d. Between the adhesive and the post.

6.2.2 Evaluation of resin tag formation

The other section of each sample was stored in 30% HCl for 24 h and in 2% sodium hypochlorite solution for 10 min, in order to completely dissolve the dental substrate and to detect resin tags and adhesive lateral branch formation. The samples were then processed for SEM observation as already described.

Serial SEM photomicrographs at x500 original magnification were taken of the canal walls at the 1, 4.5 and 8 mm levels from the end of the post. The serial photomicrographs were aligned to form a continuous horizontal examination strip at the 3 levels. Irrespective of the number of photomicrographs needed to form a complete strip, each strip was subdivided into eight “assessment units”. The density and morphology of the resin tags were then assessed.

The density and morphology of resin tags present at x500 magnifications were graded between 0 and 3. A score of 0 was assigned where resin tags were not detectable, a score of 1 was recorded when few, short resin tags (resin plugs) were visible. A score of 2 was recorded when uniform resin tags formation was seen but with a few lateral branches. A score of 3 was recorded when long resin tags with lateral branches were uniformly evident.

Higher standardized magnifications were taken in order to document resin tags and adhesive lateral branches morphology.
The scores assigned to resin tags seen at the 1, 4.5, and 8 mm levels were analyzed with the Kruskal Wallis test, in order to check for statistical significance of the differences both within and among the groups. The level of significance was set at $p=0.05$ level.

### 6.3 Results

The number of samples showing voids/bubbles within the resin cement or/and at the interface between resin cement and root walls are summarized in Table 2.

Table 2: Number of specimens in which the presence of gaps/voids/bubbles within resin cements was noted.

<table>
<thead>
<tr>
<th>Group</th>
<th>Within resin cement</th>
<th>Post/cement</th>
<th>Adhesive/cement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>1</td>
<td>1</td>
<td>/</td>
</tr>
<tr>
<td>Group 2</td>
<td>2</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Group 3</td>
<td>3</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Group 4</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

Voids were present in the composite cement layers of all groups. The cement layer was substantially similar in all groups. Between 10% (Group 1) and 30% (Group 3) of samples showed bubbles/voids within the cement. The adhesive-composite cement and composite cement-fibre post interfaces were substantially free of voids. Half of the samples in Group 2 showed voids/bubbles in the adhesive/cement layer. All groups with simultaneous curing of the adhesive and of the cement (Group 2, 3 and 4) showed a high number of voids in post/cement and adhesive/cement interfaces.

#### 6.3.1 RDIZ observations

The results obtained regarding the presence of RDIZ in the various groups under the SEM microscope are shown in Table 3.
Table 3: Scanning electron microscope evaluation of the resin dentin interdiffusion zone (RDIZ). Groups labelled with the same letter did not show any statistically significant difference.

<table>
<thead>
<tr>
<th>Group</th>
<th>Overall length of observed interface (in mm)</th>
<th>Length of interface with RDIZ (in mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 OS</td>
<td>25.5</td>
<td>22.7 (89%)</td>
</tr>
<tr>
<td>2 OS 30</td>
<td>26.5</td>
<td>18.5 (60%)</td>
</tr>
<tr>
<td>3 OS 60</td>
<td>27.0</td>
<td>18.5 (65%)</td>
</tr>
<tr>
<td>4 OS 90</td>
<td>26.0</td>
<td>18.2 (70%)</td>
</tr>
</tbody>
</table>

Group 1 - OS (control): The bonding system was light cured separately for 20 seconds.
Group 2 – OS 30: The bonding system was light cured together with the resin cement through the translucent post for 30 seconds.
Group 3 – OS 60: The bonding system was light cured together with the resin cement through the translucent post for 60 seconds.
Group 4 – OS 90: The bonding system was light cured together with the resin cement through the translucent post for 90 seconds.

The ratio between the length of the RDIZ and the total length of the interface was significantly higher in Group 1 than in the other two Groups (p<0.05). Group 1 samples had uniform RDIZ formation, while in the other groups RDIZ was less represented, especially at the apical level. In some samples of Group 2, 3, and 4, a discontinuous gap between the RDIZ and resin cement was observed. The RDIZ formation of Group 1 samples was significantly more evident than in the other three Groups (Group 2, 3 and 4). Group 4 showed a higher ratio than Group 3, which in turn presented a higher ratio than Group 2, but no statistically significant differences were found among these three Groups (p>0.05).

6.3.2 Evaluation of resin tag formation

The results obtained regarding morphology and density of resin tags are summarized in Table 4.

In Group 1 resin tags and lateral branches formation was more uniform than in the other Groups. Although the length of resin tags was more evident at the coronal third, the morphology of the resin tags was similar in all three thirds. The surface of resin tags reproducing de-mineralized tubular dentin was rough and depicted the appearance of tubular dentin dissolved by the acid. In the apical third resin tags were all approximately the same length, which was shorter than that seen in the coronal and middle third.
Table 4: Median values of the resin tags formation scores recorded at 1-, 4.5-, and 8 mm levels. (Groups labelled with the same letter did not show any statistically significant difference).

<table>
<thead>
<tr>
<th>Group</th>
<th>1 mm level (Coronal third)</th>
<th>4.5 mm level (Middle third)</th>
<th>8 mm level (Apical third)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. OS</td>
<td>2.9&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.9&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.5&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>2. OS 30</td>
<td>2.6&lt;sup&gt;a,b&lt;/sup&gt;</td>
<td>2.4&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.1&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>3. OS 60</td>
<td>2.6&lt;sup&gt;a,b&lt;/sup&gt;</td>
<td>2.5&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.3&lt;sup&gt;c,d&lt;/sup&gt;</td>
</tr>
<tr>
<td>4. OS 90</td>
<td>2.7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.5&lt;sup&gt;c,b&lt;/sup&gt;</td>
<td>1.7&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Group 2, 3 and 4: The resin tags formed in the coronal and/or middle areas of the roots were much longer than those in the apical areas. Also, the density of resin tags was higher in the coronal and middle areas than in the apical areas. In the coronal two thirds of the roots adhesive lateral branch formation was also observed. In the coronal and middle third the resin tags had a characteristic reverse-cone shape, while in the apical third this morphology could only occasionally be seen. In the apical third resin tags were often seen to only plug the tubules or were completely absent. In Group 2, 3, and 4, some ‘globuli’ were observed (Figs. 1-2). Resin tag formation was statistically significant different (p<0.05) between Group 1 and the other three groups.

6.4 Discussion

Recently, several studies have reported the quantitative evaluation of morphological observations of root canals (Ferrari et al 2001a, Ferrari et al 2001b). In this study, RDIZ formation was evaluated calculating the entire length of RDIZ formed along the interface between conditioned dentin and adhesive resin. Also the incidence of resin tags was recorded from horizontal bands around the post, 1-, 4.5- and 8- mm from the apices of the root canal preparations. In this way it was possible to statistically analyze the data obtained from SEM observations of the four different groups. This evaluation was performed because formation of both resin tags and RDIZ contribute to the mechanical bonding process to the etched dentin and consequently to the sealing process (Nakabayashi & Pashley 1998, Vichi et al.)

78
2002b). However, other issues have to be taken into account (Sano et al. 1995a, Tay et al. 1995): the ‘overwet phenomenon’ plays an important role in the quality of the RDIZ, and subsequently in the final bond strength of the adhesive system. In this paper no TEM examination and no measurement of the bond strength were performed (Sano et al 1995b, Tay et al 1996).

After light curing the bonding system from the coronal aspect of the canal (Group 1), the dentin bonding systems tested could form a RDIZ that did not interfere with the post placement into the root canal. This is most likely due to the fact that the ‘one-step’ bonding system tested in this study created a low film thickness (Vichi et al. 2002a) and the bonding system was light sensitive and could be polymerized by a light source placed at the access to the root canal (Group 1). In Group 2, 3 and 4, One Step (Bisco, Schaumburg, IL, USA) was not light cured before applying the resin cement and the post, but adhesive materials were light-cured through the post simultaneously, shortening the clinical procedure.

An important issue related to the clinical procedure is the care taken to remove excess adhesive that, once cured, could interfere with the adaptation of the post to the prepared dowel space. Even though all the samples were prepared by the same operator, following the same procedure and using the same instruments, some variability in the cement thickness was expected and actually observed as a result of the naturally occurring variability in root canal shape.

It is always questionable whether an interfacial gap seen under the SEM is an artefact due to specimen preparation. However, as most of these gaps were consistently and locally concentrated in the apical third, the least accessible area of the canal, it can be speculated that they were real gaps revealing an adhesion mechanism of poor quality.

A different density and morphology of resin tags and adhesive lateral branches at the three horizontal bands could be found in Group 1 as compared with Group 2, 3 and 4 samples. These three last Groups always had poorer results when compared to the standardized technique for bonding fibre posts into root canals (Group 1). Even when the exposure time to the light curing procedure was increased (Groups 2, 3 and 4, from 30 to 60 and 90 s respectively), the increase in the scores was not statistically significant. Group 1 samples always had better results than samples
from the other three Groups. This may be due to a difference in the procedure, for example, although it has been demonstrated that a proper light curing of resin cement can be obtained in an experimental model (Boschian et al. 2001), it is possible that light transmission through the post might not be sufficient to light-cure the cement and the adhesive in the same step. The adhesive may be subjected to an inadequate intensity of light and thus not be completely cured, thus leaving ‘unpolymerized’ adhesive resin. Even when increasing the light-exposure time, from 30 s (Group 2) to 60 s (Group 3) and to 90 s (group 4), uncured resin globuli were still present. This could account for a reduction in resin tag formation and the poor results presented in Table 4. This problem is supported by the finding of other studies (Tay et al 1995).

Another factor affecting RDIZ and resin tag formation can be the viscosity of the cement and its adaptation to prepared canal space. If the adhesive solution is not light-cured before the application of the cement, a good adaptation to the root canal walls is not achieved, and the RDIZ is not established adequately. Under these conditions, when the cement is placed together with the post, the cement itself may wash out the adhesive.

In all the four Groups a microbrush was used. The importance of this device in reaching the narrowest and deepest portions of the root canal preparations has been showed by recent findings (Ferrari et al 2001b, Vichi et al 2002b). The microbrush is able to reach all the prepared root canal dentin, and to apply a certain pressure on the adhesive solution, so as to maximize its penetration into the etched substrate. This results in a deep diffusion of resin into the tubules and in the formation of lateral branches (Chappel et al. 1994, Mjor & Nordhal 1996).

The absence of voids/bubbles at fibre post/resin cement interface could be related to the good bond between the resin matrix of the post and that of the resin cement, whereas the presence of voids/bubbles within the resin cement might be mainly due to the viscosity of the resin cement and to the anatomy of the root samples. In fact, anatomical variations of roots, the consequent variable amount of resin cement, and its distribution into a prepared canal space could be other possible causes of void formation. Discrepancies between root anatomy and post shape might account for the clinical finding that the weakest point of fibre post/resin cement/adhesive
material/etched dentin system is the link between resin cement and the post (Ferrari & Scotti 2002). The high percentage of voids/bubbles found in Group 2, 3 and 4 shows that several factors (light intensity, cement viscosity etc.) interfere with the complete setting of the materials used, as compared with Group 1, where a traditional technique was used and a lower number of voids were detected. No data are available regarding a calculation of the percentage of light passing through the post and reaching the apical area. However in order to improve the predictability of the one-step technique, it would be desirable for the manufacturers to provide translucent posts able to transmit a high intensity of light from coronal to apical areas. Of course, the amount of light emitted by the light source is important, ideally the light transmitted to the post should be such as to ensure an adequate degree of polymerisation in the apical third, without resulting in an augmented polymerisation shrinkage in the presence of unfavourable configuration factor that occurs in the root canal (Feilzer 1987).

The microscopic observations in this study and their quantitative evaluations does not provide information on the quality of RDIZ. It has been shown recently (Mason 2001) that collagen fibres can be denaturated in direct correlation with the time passed after root canal treatment. In recently treated teeth a wide and dense collagen fibre network could be noted. On the contrary, when the treatment had been performed more than 5 years previously, the collagen fibres appeared shorter, and their organization and uniformity was lost. This denaturation of collagen fibres can be related to the loss of organic tissue turnover after root canal treatment.

6.5 Conclusions
The null-hypothesis tested in this study was not confirmed. The one-step (‘one-shot’) technique, used for luting translucent fibre posts into root canal preparations proved to be less effective than the traditional technique in forming resin tags, adhesive lateral branches and RDIZ.
Fig. 1: Group 2 sample, apical third. Resin globuli closely attached to the resin tags are noted (original magnification x 2500).

Fig 2: Higher magnification, Group 4 sample (original magnification x 5000). These globuli, probably formed by unpolymerized resin, can be due to an uncomplete curing of the adhesive material when it is not light cured before the placement of the resin cement and the post.
References


Chapter 7 Anatomic Post: an innovative approach

Fibre posts went through rapid developments in the last few years. These changes regarded essentially three main issues: materials, radiopacity and shape. Starting from carbon fibers, glass and quartz fiber are now widely used, and the addition of strontium to the resin components radiopaque fiber posts are now available. The optical property of translucency has also been appreciated by clinicians, allowing the use of dual-curing resin cements for luting purposes. Interestingly, starting from the double-cylinder shape, endodontic shapes and then double tapered shapes were presented, as the adhesive cementation now relies more on formation of resin dentin interdiffusion zone and resin tags rather than on the good fitting and mechanical retention of the post inside the root canal (Ferrari et al 2002). It is a clinical evidence to encounter debondings, of the post or of the core, during temporary phase (Ferrari et al 2000). An excess thickness of the cement, especially at the coronal level, can generally be regarded as the main cause. As a matter of fact it is pretty common to face root canals that are not perfectly round after endodontic instrumentation. This chapter presents an in vitro and an in vivo study regarding the very last brand of fiber post available (Anatomic Post’n Core, RTD, St Egrève, France), that is able to reduce the cement thickness and to immediately restore the coronal portion in cases where the root canal is not round and a huge loss of tooth structure is present.

7.1 SEM evaluation of the cement layer thickness after the luting procedures of two different posts

The increasing popularity and wide-spreading use of fiber posts is inevitably changing the procedure of reconstructing endodontically treated teeth. Since fiber posts introduction in 1990 (Duret et al 1990), many investigations have confirmed the good clinical performance of the system adhesive- resin cement- fiber post (Ferrari et al 2000a, Fredriksson et al 1998) due to its good retention value Asmussen et al 1999, Drummond et al 1999) and low stressing behaviour (Rengo et al 1999).

The evolution of fiber posts has received an acceleration since Carbon and quartz fiber posts have been replaced by glass fiber posts that are translucent and often radiopaque. Also the shape of these posts have changed: from a double-cylinder,
thus designed for retention purposes, cylindrical (Endopost) and conic profiles (DT posts) have been developed, based on the good performances of the new bonding procedures (Kurtz et al 2002).

The property of translucency reveals favourable for luting purposes, as the transmission of light through the post allows the clinician to use also dual-cure cements (Grandini et al 2003, Sawada et al 2002). Moreover, the wider choice of available shapes permits to limit the amount of residual dentin that has to be removed in order to achieve a satisfactory post adaptation.

Furthermore, the translucent fiber post has a modulus of elasticity similar to that of dentin and of the other posts, and has indeed given proof of adequate mechanical properties (Drummond et al 1999). The use of ‘one-bottle’ adhesive systems has greatly simplified the procedure of bonding also into root canals, and has proved to be clinically adequate (Ferrari et al 2001a and 2001b), especially when a microbrush, in the place of a regular brush, is employed as a carrier of the adhesive and the resin cement inside the root canal (Ferrari et al 2001b).

Clinical studies (Fredriksson et al 1998, Malferrari et al 2002, Scotti et al 2002) have revealed that when using fiber posts, the most common cause of failure is not root fracture, as it happens with metallic or cast posts, but debonding. Also endodontic failure is an important issue (Tronstad et al 2000), and a reliable predictor of the success rate of many kind of reconstructions; although the removal of a fiber post is easier than that of any kind of metallic posts (de Rijk et al 2000), thus offering the clinician a chance of retreatment. Debonding is more likely to occur in the absence of the desirable ‘ferule effect’, or in the presence of a too thick layer of cement (Ferrari et al 2000a). In particular, if the post is not well fitting, especially at the coronal level, the cement layer ends up being too thick, and bubbles are likely to be present within it, all this predisposing to a debonding.

Clinically, when debonding occurs, the post often appears lined by cement still adhering to it. In this case it is possible to lute again this cement-relined post, which is now “anatomic”. This individual post, shaped to the root canal space ends up having a better fit than any other prefabricated post (Ferrari et al 2000a). This opportunity is particularly appreciated when dealing with root canals which have an elliptic shape, such as canines, lower premolars etc. In these cases the
clinician is forced to adapt the residual root structure to the post shape, through the removal of a further amount of dentin. On the contrary, it would be desirable that the post adapt to the root canal anatomy as produced by the endodontic treatment. This is indeed the rationale for the creation of an anatomic post (Boudrias et al 2001a and 2001b).

It goes back to two years ago the first documented attempt to make anatomic posts by relining a quartz post with self-curing resin and a translucent post with light-curing resin (Boudrias et al 2001a, Ferrari et al 2002, Grandini et al 2003). This way the authors were able to achieve a better adaptation of the post to the residual root canal anatomy. Recently the Anatomic Post’n Core (RTD, St Egrève, France) has been introduced (Ferrari et al 2002). This new post is made by a DT post n. 1 that is covered by a light-curing resin (Lumiglass, RTD, St Egrève, France).

The clinical procedure for the use of this post starts with the fitting of the Anatomic post (post plus resin) into the root canal, after having eliminated with a drill all the possibly present undercuts from the canal walls, and having lubricated them with a glycerine gel. When the anatomic post is introduced into the root canal, the resin surrounding the post is able to reline the post itself, thus creating a new post whose adaptation is expected to be better than that of any prefabricated post. A twenty-second light-curing through the post allows the resin surrounding the post to set, then the Anatomic post is removed and fully light cured for other twenty seconds. Now the post has to be tried in, to make sure that no interference exists to its easy placement. At this point the usual procedure for luting a translucent post can be followed.

**Aim of this study** was indeed to evaluate the resin cement thickness after luting anatomic posts and standardized fiber posts into root canal preparations.

The null hypothesis that similar resin cement thicknesses were present when anatomic or standardized posts were used was evaluated.

In addition, the presence of voids and/or bubbles within the luting material or at the interface between the cavity walls and the post was verified, and the uniformity and morphologic characteristics of the resin-dentin interdiffusion zone were analyzed under a scanning electron microscope, as parameters usually assessed when judging

7.1.1 Materials and Methods
Twenty upper anterior teeth, extracted for periodontal problems, were selected for this study. The teeth were endodontically instrumented at a working length of 1 mm from the apex to a #35 master apical file. A step-back technique was used with stainless-steel K-files (Union Broach, New York, NY, USA), gates Glidden drills #2 to #4 (Union Broach, New York, NY, USA), and a 2.5% sodium hypochlorite irrigation. The prepared teeth were obturated with thermoplasticized, injectable gutta-percha (Obtura, Texceed Corp., Costa Mesa, CA, USA) and a resin sealer (AH-26, DeTrey, Zurich, Switzerland).

The root canal walls of each specimen were enlarged with low-speed drills provided by the manufacturer (RTD, St Egrève, France), and the depth of the post space preparation was 9 mm from the cementum-enamel junction. The sample was randomly divided into two groups of ten specimens each.

Group 1: The first ten specimens were treated with the One Step bonding system (Bisco, Schaumburg, IL, USA), following manufacturer’s instructions. The root canal walls were etched with 32% phosphoric acid (Bisco, Schaumburg, IL, USA) for 15 seconds, washed with a water syringe, and then gently air-dried. Excess water was removed from the post space using paper points. Four to five coats of primer-adhesive material were applied into the root canals with a microbrush provided by the manufacturer. Excess primer-adhesive solution was removed with a paper point, the remaining material was gently air-dried, and then light-cured for 20 seconds. Duo-Link (Bisco, Schaumburg, IL, USA), a new dual-cure resin cement was used. The catalyst and base components of the material were mixed according to the manufacturer’s instructions. The resin cement was applied into the root canal space with a lentulo drill, and the fiber post was seated. The excess resin was removed and the remaining material light-cured for 20 seconds through the post.

The DT translucent fiber posts (RTD, St Egrève, France) were used. They were available in three different sizes (DT1, 120 tip diameter, 10% conicity; DT2, 100 tip diameter, 08 % conicity; DT3, 90 tip diameter, 06 % conicity). The choice between
them was dictated by the size and the shape of the roots, the objective being the achievement of a good fit of the post at the apical portion of the canal. The length of each post was controlled and the post was properly cut before luting.

Group 2: The other ten specimens were used for testing ‘experimental anatomic posts (RTD, St Egrève, France)’, following manufacturer’s instructions (Fig 1). After lubricating the canal walls with a glycerin gel, the anatomic post was fitted into the root preparation, and irradiated by the curing light for 20 seconds. Then the post was removed and fully light-cured for other 20 seconds. The post was tried in the root canal again, in order to check for its easy insertion, without any interference. An abundant rinsing was performed to remove the excess of the lubricant gel. Finally, the post was luted following the same technique already described for Group 1 specimens, which involved phosphoric acid etching of root canals, followed by the application of the One-Step adhesive system, and of the Duo-Link resin cement.

The sample teeth were stored in a water solution at room temperature. A week later, the root specimens were sectioned parallel to the long axis of the tooth, by means of a diamond saw (Isomet, Buhler, Lake Bluff, NY, USA).

7.1.1.1 Resin cement thickness

The sections were gently decalcified (32% phosphoric acid was applied for 30 seconds, then the sample was washed and gently air-dried) and deproteinized (the sample was immersed in a 2% sodium hypochlorite solution for 120 seconds), in order to clean the surface from any debris.

Specimens were at this point dehydrated with alcohol, sputter-coated with gold (Edwards Ltd., London, UK), and observed under a scanning electron microscope (Philips 515, Philips Co., Amsterdam, The Netherlands) at different standardized magnifications (x250, x500, x2300 and x4580 for resin tags; x625 and x1310 for resin dentin interdiffusion zone).

Serial SEM photomicrographs of the canal walls were taken at the 1-, 4.5- and 8-mm levels (x500 magnification) (Fig. 2). The photomicrographs were aligned to form a continuous horizontal examination strip at the three levels. Irrespective of the number of photomicrographs needed to form a complete strip, each strip was
subdivided into eight “assessment units”. In each assessment unit two distinct operators in double blind evaluated the following aspects:

1. Resin cement thickness at the three different levels.

The differences in the cement layer thickness surrounding the two types of posts at each of the three root canal levels were tested for statistical significance (t-Test, p=0.05). Also, within the same group of samples and therefore for each type of post, the differences among the cement layer thicknesses measured at the three checked levels of the root canal were evaluated statistically (One-Way ANOVA, p=0.05). Additionally, the Fisher’s Exact test was applied to check for statistical significance of the differences in frequency of defects between the two experimental groups (p>0.05).

7.1.2 Results

The cement thickness measured in microns in the two groups of specimens is reported in Table I.

Table I: Mean and standard deviation values of resin cement thickness (in µm) recorded at 1-, 4.5-, and 8 mm levels. The values labeled by the same letter were not significantly different.

<table>
<thead>
<tr>
<th>Group</th>
<th>1mm level (Coronal third)</th>
<th>4.5mm level (Middle third)</th>
<th>8mm level (Apical third)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. control</td>
<td>610±67&lt;sup&gt;a&lt;/sup&gt;</td>
<td>240±21.6&lt;sup&gt;b&lt;/sup&gt;</td>
<td>130±10.4&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>2. anatomic posts</td>
<td>20±2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>40±3.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>100±8.2&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

It can be noted that the resin cement thickness decreases from the apical to the coronal level in the anatomic samples, while the opposite happens in the control group (Figs. 3 and 4).

In Group 2 the highest thickness of cement (around 100 microns) was seen at the margin between the coronal portion of the anatomic post and the resin composite abutment (Fig. 5).
Statistically significant differences in cement thickness were found between the two groups of specimens at the coronal and the middle level of the canal (p<0.05). Also, within the same group of specimens, cement thicknesses at the three different levels of observation were significantly different (p<0.05). Only in the presence of anatomic posts, were similar thicknesses of cement measured at the coronal and middle third of the canal (Fig. 6) (Table I).

A good adaptation of the fiber post, relining material, luting material and residual dentin could be noted (Fig. 7).

Often voids and bubbles were detected within the resin cement (Table II), as well as within the abutment in both groups of specimens (Table III). Also, voids and bubbles were noted between the fiber post and the resin material.

Table II: Number of samples in which presence of gaps/voids/bubbles within resin cements was noted along the root canal preparation

<table>
<thead>
<tr>
<th></th>
<th>Within resin cement</th>
<th>Post/resin material</th>
<th>Dentinal walls/cement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>5</td>
<td>/</td>
<td>3</td>
</tr>
<tr>
<td>Group 2</td>
<td>1</td>
<td>1</td>
<td>/</td>
</tr>
</tbody>
</table>

Table III: Number of samples in which presence of gaps/voids/bubbles within the abutment was noted.

<table>
<thead>
<tr>
<th></th>
<th>Within resin material</th>
<th>Post/resin material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>Group 2</td>
<td>9</td>
<td>2</td>
</tr>
</tbody>
</table>

Occasionally, gaps of different extension were observed between the resin composite relining material and the fiber post (Table II).

The differences in frequency of defects between the two experimental groups were not statistically significant (p>0.05).
7.1.3 Discussion

SEM observations allow for a high resolution assessment of the conditions of adhesion. The morphologic characteristics of the adhesive interface, as revealed by scanning electron microscopy, can be evaluated through either a qualitative or a quantitative analysis. The latter is usually preferable, as it provides a repeatable method. For this reason, in the present study it was chosen to follow a recently proposed quantitative analysis (Ferrari et al 2001b), for the evaluation of cement thickness, as well as of the frequency of structural discontinuities in the adhesive interface, such as bubbles, voids or gaps. This evaluation was performed because formation of both resin tags and RDIZ contribute to creating a proper mechanical bonding to etched dentin and consequently sealing it (Nakabayashi et al 1998, Vichi et al 2002a). TEM examination and measurement of the bond strength are the best way to assess the quality of the resin-dentin interdiffusion zone (Sano et al 1995, Tay et al 1995). However, even if the SEM evaluation of RDIZ is not the best way to measure the quality of the adhesion, it eventually gives quantitative information on its uniform formation.

The clinical steps needed to create the anatomic post have been described. The technique is relatively easy, and adding only few more actions to those required to bond a regular translucent fiber post, allows to achieve a superior quality of the fitting, and to considerably reduce the thickness of the cement layer, within which the development of voids or bubbles is less likely.

The expected advantages of this technique can be listed as follows: as a result of the relining, the thickness of the cement layer is lower and constant; the formation of bubbles or voids, representing areas of weakness within the material, is less likely in a thin and uniform layer of cement; the polymerization stress that develops within a low-thickness film of cement is minimal; furthermore, from a clinical point of view, in a root canal that ends up, after the endodontic treatment, being conic-shaped or not perfectly round, the possibility of relining the Anatomic post is appreciated: the post adapts to the canal instead of trying to adapt the root canal to the standardized post (Grandini et al 2003). Of course these advantages must be verified by further studies as no statistically significant differences were evident between the two groups.
In comparison with metallic posts, the anatomic post offers the same advantages as all of the other fiber posts, including the fact that, in case endodontic retreatment is needed, a fiber post is more quickly and easily removed than a metallic post (Tronstad et al 2000). Also the considerations regarding chair-time and costs required by the two compared procedures for restoring endodontically treated teeth tend to tip the balance in favor of fiber posts, as the use of these, differently from cast posts, allow to bond the post and build the core in only one visit, without any laboratory phase and fee.

Whether a light-curing cement can be adequate for luting fiber posts or it is safer to resort to a dual-cure material is still debated in the literature, the heart of the issue being light transmission through the post. In other words, according to some Authors the amount of light that, passing through the post, gets to the apical portion of the post is not enough to adequately cure a light-activated resin cement (Rovatti et al 2001). Some other researchers, on the other hand, state that transmission through a translucent post is efficient enough to allow also the apical portion of the post to be reached by a light intensity sufficient to induce polymerization (Boschian et al 2001).

As far as the anatomic post is concerned, the issue of light transmission through its relining resin has still to be investigated. The question whether light absorption through the relining resin may negatively affect the polymerization process of the cement can in fact be raised. In the wait for scientific data that will answer the question, it remains safer and advisable to use a dual-curing resin cement for luting anatomic posts.

Just like all of the resin-based materials, also the relining resin surrounding the anatomic post shrinks as it cures. Although this aspect needs further evaluation, however, it logically seems that the shrinkage should favor the extrusion of the anatomic post from the canal after its relining.

The quality of the adhesion between the post and the relining resin appeared good in all of the SEM views. This may be due to the compatibility between the two materials, which have the same matrix components, as well as to the addition of a coupling agent (silane) at the interface between the post and the relining resin.
Regarding the wider thickness of the resin cement layer found with the standardized post, the references from the literature do not give a certain answer. Some clinical works, perspective or retrospective studies (Ferrari et al. 2000a, Fredriksson et al. 1998, Malferrari et al. 2002, Scotti et al. 2002), show that debonding occurs when a thicker cement layer is present. In this sense it can be assumed that a more precise fitting obtained with the anatomic post can improve this aspect, even if a further clinical control study is needed to confirm this aspect.

The null-hypothesis tested in the study was not confirmed. The resin cement thickness was significantly lower in the ‘anatomic post’ group than in the control group (standardized posts), except at the apical third of the canal, where there was no statistically significant difference. Although there is no scientific evidence that a thinner layer of cement can improve the quality of the luting procedure, a good adaptation of anatomic posts was evident in all of the specimens, allowing the post to stand still during the luting procedures.

The clinical procedure to make an anatomic post was effective and easy to perform.

7.2 Use of Anatomic Post’n Core for reconstructing an endodontically treated tooth: a case report.

The introduction of fiber posts has had a great impact on the clinical procedures to restore endodontically treated teeth. Since their début at the beginning of the 90’s (Duret et al. 1990), the research behind these products has continuously worked on modifying the type of fibers (from carbon to quartz, to glass), as well as the shape of the posts. The evolution in the technology has enabled the manufacturers to provide today fiber posts that, beside offering superior esthetic and mechanical properties, which had been the first qualities to be appreciated in comparison with metal or cast posts, are also radiopaque and available in a great variety of shapes (Asmussen et al. 1999, Asmussen et al. 1999, Fredriksson et al. 1998). The growing popularity of fiber posts witnesses their clinical success, and the results of longitudinal trials (Ferrari et al. 2000, Malferrari et al. 2002, Scotti et al. 2002, Fredriksson et al. 1998) confirm their reliability.
As regards in particular the shape of the posts, the evolution has gone from the
double-cylinder of the carbon posts, thus designed for retention purposes, to the
cylindrical or the conic profile of the Endoposts and DT posts respectively. These
latter designs are meant for a better adaptation of the post to the canal anatomy, thus
minimizing the amount of residual root structure that has to be sacrificed in order to
get the post to fit. Obviously, this trend toward more and more conservative root
preparations for post adaptation has been possible only thanks to the contemporary
progress in the field of materials and techniques for bonding, that has made adhesion
to root canal walls safer and more predictable (Ferrari et al 2001a, 2001b and 2002b,
It is likely that a further significant improvement in fiber posts adaptation and
retention will be achieved with the so-called ‘anatomic post’. This is a translucent
fiber post covered by a layer of light-curing resin (Anatomic Post’n Core. RTD),
which allows for a relining of the post through its insertion into the canal, with the
aim of achieving a better fit than that possible with any prefabricated post (Grandini
et al 2000, Ferrari et al 2002a). As a result of its precise adaptation to the root canal
space, the relined post is going to be surrounded by a thin and uniform layer of resin
cement, which creates ideal conditions for post retention (Boudrias et al 2001).
The procedure of ‘individualizing’ the post through its relining, although advisable
in all cases, appears to be particularly effective for the purpose of improving post
retention when dealing with canals of elliptic shape, or exhibiting a reduced amount
of residual root structure after endodontic treatment; this latter situation obviously
contraindicates a further removal of dentin to make the canal shape match the post
shape. The creation of an ‘anatomic post’, involving the opposite adaptation, that is
shaping the post to the root anatomy, is the procedure of choice in these clinical
situations, of which the described case is an example.

7.2.1 Case report
A nine-year old patient comes to the office two days after having hit his front teeth
as a result of falling down while playing in the school gym. The trauma caused a
complicated crown fracture with extensive pulp exposure on teeth 1.1 and 2.1, and
an enamel-dentinal fracture without pulp exposure on tooth 2.2. After clinical and
x-ray examination, it was decided to endodontically treat teeth 1.1 and 2.1, and to restore all the teeth with resin composites, waiting for the adequate time to perform a prosthetic treatment. The root canal treatments were done, and tooth 1.1 was restored with a direct resin composite restoration (Figs. 8 and 9). On tooth 2.1, the root canal anatomy after endodontic treatment was such that no prefabricated post could satisfactorily adapt to it (Fig. 10); on the other hand, the amount of residual dentin on the canal walls was such as to contraindicate the further removal of tissue, to make the canal shape adapt to that of the post. It was then decided to use for tooth 2.1 an ‘anatomic post’. The procedure started with removing by means of a drill any undercut still possibly present on the canal walls, which were then lubricated with glycerine. At this point the anatomic post’n core was inserted (Fig 11) and light cured for 20 seconds (Fig 12). Then the anatomic post was gently pulled out of the canal, and an additional 20-second light curing was performed in order to completely polymerize the relining resin (Fig 13). The anatomic post was tried in again, in order to check for its easy insertion, without any interference. At this point a luting procedure was performed similar to that recommended for a regular translucent post. The root canal walls were etched with 32% phosphoric acid (Bisco) for 15 seconds, washed with a water syringe and gently air-dried. Excess water was removed from the post space using paper points (Mynol). Four to five coats of the One Step bonding system (Bisco) were applied into the root canals with a microbrush provided by the manufacturer. The excess primer-adhesive solution was removed with a paper point (Mynol), gently air-dried, and then light-cured for 20 seconds. Dual Link (Bisco), a new dual-cure resin cement was used for luting. The catalyst and base components of the material were mixed and applied following manufacturer’s instructions. The resin cement was carried into the root canal space with a lentulo drill, the post was seated, and the excess of material removed before light-curing for 40 seconds through the post (Fig 14). Due to the young age of the patient, it was decided to avoid the immediate preparation for a prosthetic crown. The anatomic post was therefore simply used as a base for a direct composite restoration (Fig. 15). The prepared tooth was etched with 32 % phosphoric acid (Bisco) (Fig. 16); then, the One step adhesive system (Bisco) was applied as
recommended by the manufacturer (Fig 17), and the restoration was completed with a microhybrid resin composite material (Micronew, Bisco) (Figs. 18, 19 and 20).

7.2.2 Discussion

The observation of a residual root canal shape after endodontic treatment which is not perfectly round is not so uncommon (Davis et al 1972, Walton et al 1996). This case is a suitable situation for using the Anatomic post. In fact, in the attempt to place a regular fiber post in a thus shaped canal, one would be forced to round up the canal walls with burs, thus sacrificing a conspicuous amount of the residual tissue, or would end up applying a thick layer of cement, to fill up the spaces between the loosely fitting post and the canal walls. The latter is a predisposing situation to failure of the adhesion and debonding of the post (Ferrari et al 2000). On the other hand, a post relined to closely match the shape of the canal will be surrounded by a thin and uniform film of cement, which represents an ideal situation for retention purposes.

In addition, the technique of the anatomic post allows to perform a direct restoration on an ‘individual’ post in only one visit and without the laboratory involvement, whereas the classic post and core system, direct or indirect, requires at least two visits and a laboratory phase. This opportunity is particularly appreciated in a case like the one described, where the young age of the patient calls for a treatment to be completed in few visits, each one as quick and easy as possible.

On the other hand, if a prosthetic restoration is planned for the endodontically treated tooth, it is possible to immediately build up on the anatomic post a resin composite core, which in the same visit can be prepared for prosthetic purposes.

From a clinical point of view, it appears that the step of creating an individual post by letting the surrounding resin reline it according to the canal shape, adding only five minutes of chair-time to the standard procedure for luting a translucent post, can greatly improve post adaptation and retention. A study involving both an in vivo trial and a SEM evaluation of the quality of adhesion is already available (Grandini et al 2004), with the aim of providing some more scientific support to the positive clinical impression.
7.2.3 Conclusions

The clinical procedure of the Anatomic post can be used for reconstructing an endodontically treated tooth when the resulting anatomy of the root canal walls is not perfectly round, and when there’s an important loss of substance at the coronal level. This way it is possible to obtain a superior fitting of the individual anatomic post, as compared with any other prefabricated fiber post.
Fig 1: Shape of the Anatomic post in comparison with that of DT posts of different sizes (DT1, 2, and 3).

Fig 2: picture showing the three levels of observations: apical, medium and coronal level (original magnification x13).
Fig 3: Group 2 sample. Low magnification image showing the relining provided by the light-activated resin surrounding the post (original magnification x 13).
Fig 4: Group 1 sample. An abundant amount of cement can be noted around the fiber post (original magnification x 21).

FP: fiber post, D: Dentin, LC: luting cement
Fig 5: Group 2 sample. A thicker layer (arrows) of cement (C) is visible at the interface between the abutment and the coronal dentin (original magnification x 170).
Fig 6: Picture showing the presence of voids/bubbles within the resin material (original magnification x 11).
Fig 7: High magnification picture showing the good quality of the adhesion between relining material (RM), luting material (between arrows) and root canal dentin (D) (original magnification x 356).
Fig 8: x-ray examination after having completed the endodontic treatment.

Fig 9: Endodontic treatment and a direct composite restoration were performed on teeth 1.1 and 2.1.

Fig 10: After rubber dam placement, the wide and not perfectly round residual root canal anatomy is visible on tooth 2.1.
Fig 11: The post surrounded by light-curing resin is inserted into the root canal with the aim of relining it (Anatomic Post).

Fig 12: Light-curing through the post (20 seconds) to allow for the setting of the surrounding resin.

Fig 13: The relined post as it appears after having completed the light-curing out of the patient’s mouth.
Fig.14: The post after the luting procedures.

Fig.15: View of tooth 2.1 after preparation for a direct restoration. The anatomic post is used as a ‘base’ for the resin composite restoration.

Fig.16: Etching procedure with phosphoric acid.
Fig 17: Opaque resin composite is used to build the core of the tooth and to obtain the proper effect of opacity or to reproduce the natural opacity of the tooth.

Fig 18: The restoration is completed with a translucent resin composite, used as ‘enamel’ material.
Fig 19: Post-operative x-ray examination. The anatomic post has been luted into the root canal, and the restoration completed.

Fig 20: Facial view immediately after the removal of the rubber dam.
References


Ferrari M, Vichi A, Grandini S, Davidson C. ‘One-bottle’ and three step adhesive systems used for bonding fiber posts into root canals under clinical conditions: an SEM investigation. Dent Mat, 2002b.


Tronstad L, Asbjornsen K, Doving L, Pedersen I, Eriksen HM. Influence of coronal


Chapter 8  Clinical aspects and future role of fiber posts in dentistry

In the last 10 years the use of fiber posts for restoring root canal treated teeth has increased in popularity. The major advantage is their similar elastic modulus to dentin, producing a stress field similar to that of natural teeth, whereas metal posts exhibit high stress concentrations at the post-dentin interface (Pegoretti et al 2002). Some authors emphasize this fact by calling “low modulus” restorations those made with a fiber post, and “high modulus” those made with rigid posts (metal, alloys, zirconium etc.) (Ferrari et al 2002). It has also been reported that using a “low modulus” restoration could reduce the risk of root fractures (Isidor et al 1996, Akkayan et al 2002). Clinical studies have also demonstrated high success rates without the occurrence of root fractures (Ferrari et al 2000a and 2000b). Many clinical studies are available regarding the use of fiber posts, a resin core and a crown (Scotti et al 2002, Malferrari et al 2002, Ferrari et al 2000a and 2000b, Dallari et al 1998, Monticelli et al 2002).

With the use of contemporary restorative techniques, it is possible to restore teeth with direct composite procedures, with good functional and esthetic outcomes, and in a way to save tooth structure. Indications for their use have expanded enormously in recent years, and now include restoration of tooth structure and contour, changes to tooth form and enhancement of esthetics, combination restorations (Hickel et al 2004).

This chapter analyses a possible future use of fiber posts in combination with a direct resin crown for the restoration of root canal treated teeth, according to the aim of the minimal intervention philosophy (Mjor et al 2002).

8.1. Clinical evaluation of the use of fiber posts and direct resin restorations for endodontically-treated teeth

The potential of utilizing fiber-reinforced materials in restorative dentistry has been appreciated for some time (Bradley et al 1980). The introduction of carbon fiber posts in 1990 (Duret et al 1990) provided the dental profession with an alternative to cast or prefabricated metal posts for the restoration of endodontically-treated teeth, as the elastic moduli of these fiber posts are closer to that of dentin when compared
with the metal posts (Asmussen et al 1999). Although these earlier generations of fiber posts yielded promising results in clinical trials (Fredriksson et al 1998, Ferrari et al 2000a and 2000b), they suffered from the limitations of being radiolucent and difficult to mask under all-ceramic or resin composite restorations (Vichi et al 2000).

Over the years, there has been a rapid development in fiber post technology. With the more recent introduction of radiopaque and more aesthetic quartz and glass fiber post systems, there is a continuing improvement in the acceptance of fiber posts by the dental profession (Ferrari et al 2000a, Drummond et al 1999). Studies on the adhesion of fiber posts to root dentin Nakabayashi et al 1998, Chappel et al 1994, Mjor et al 1996), the different luting procedures (Ferrari et al 2000c, Vichi et al 2002) and the abutment build-up (Gateau et al 1999, Cohen et al 1996, Freedman 2001) demonstrated the quality performance of the new generations of fiber posts (Dietschi et al 1997). These favorable results are also supported by clinical trials showing the absence of tooth fracture when fiber posts are used for restoration of endodontically-treated teeth (Monticelli et al 2003, Ferrari et al 2000a and 2000b).

The need for crown coverage after root canal treatment is still conjectural, and no recent clinical study is available to confirm the indications given in the literature (Sorensen et al 1984, Paul et al 1998). Post placement and root canal treatment are usually considered the major etiological factors for root fractures. For this reason crown coverage has always been highly recommended (Fuss et al 2001). An association between crown placement and the survival of endodontically-treated teeth was observed when the loss of tooth structure was remarkable (Aquilino et al 2002, Newman et al 2003). However, the mode of failure or deflection of bonded fiber-reinforced composite posts demonstrated that they are protective of the remaining tooth structures, and fracture usually comes about at loads that rarely occur clinically (Paul et al 2001). Although retrospective studies reported good clinical performances when a crown was used after tooth build-up (Monticelli et al 2003, Ferrari et al 2000a and 2000b), no clinical study was available to confirm the performances of fiber posts when they are used in conjunction with direct resin restorations. Thus, the aim of this study was to evaluate the results of a clinical
evaluation on root-treated teeth that were restored using fiber posts and direct resin restorations without additional crown coverage.

8.2 Materials and Methods

Eighty-one patients who required endodontic treatment and restorations on 38 anterior teeth and 62 posterior teeth (33 premolars and 29 molars) were recruited for this study. Clinical and radiographic examination demonstrated the need for root canal treatment in these 100 teeth. The treatment and recall protocol was approved by the ethical committee from the University of Siena, Italy, and the patients’ informed consent was obtained before enrolment in the clinical evaluation. The endodontic procedure was performed using a crown-down technique. A portable E-Master (VDW GmbH, Munich, Germany) endodontic motor was used and speed rotation and torque were adjusted according to manufacturer’s indications. A chelating agent (FileCare EDTA, VDW GmbH) and 2.5% sodium hypochlorite (NaOCl) were used to clean the pulp chamber at the beginning of the instrumentation. In addition, 2 ml of NaOCl were delivered to the pulp chamber after the use of each file. All teeth were instrumented with Flexmaster instruments (VDW, Germany). These instruments’ philosophy is based on the crown down approach, and they include an “introfile” for the enlargement of the coronal end, a 35.02 file and three different tapers (0.6, 0.4, 0.2) for 30, 25 and 20 files. The working sequence, proposed by the manufacturer, is based on the degree of the curvature: canals are divided in wide, medium and narrow canals. For all of them, a guiding path for the insertion of a size 10 manual file to the working length was created. Then the sequence was changed depending on the size of the canals.

- wide canals: intro file, 30.06, 25.06, 20.06, 30.04.
- medium canals: intro file, 25.06, 20.06, 30.04, 25.04 (then 25.02, 30.02 and 35.02 if needed).
- narrow canals: intro file, 20.06, 30.04, 25.04, 20.04 (then 20.02, 25.02, 30.02, 35.02 if needed).

The prepared canals were obturated with gutta-percha points (Mynol, Block Co, Jersey City, NJ, USA) and an epoxy resin sealer (Pulp Canal Sealer, Kerr, Romulus, Michigan, USA) using a warm vertical compaction technique. Then the root canal walls were enlarged with a low-speed bur provided by the manufacturer. The depth
of the post space preparation was 9-10 mm. The root canal walls were etched with 37% phosphoric acid (Bisco Inc., Schaumburg, Illinois, USA) for 15 seconds, washed with water spray and then gently air-dried. The excess water was removed from the post space using paper points (Mynol). Subsequently, One-Step (Bisco) adhesive was applied with a microbrush in two consecutive coats, gently air-dried and the pooled adhesive left in the post space was removed using a paper point before light curing for 20 seconds. Then a dual-cure resin cement (DuoLink, Bisco) was used to perform the luting procedure with translucent glass fiber posts (DT post, RTD, St Egrève, Grenoble, France). According to the diameter of the canal, either DT size 1, 2 or 3 was used. The cement was applied with a lentulo spiral into the post space, and the post was inserted into the canal. Resin cement excess was removed with a clean microbrush and then the cement was light-cured for 40 seconds. The restorative procedure was completed by building up the tooth with a direct composite restoration (Gradia Direct, GC Corp., Tokyo, Japan) using the appropriate shades. As far as anterior teeth were concerned, both opaque dentin, enamel and translucent enamel shades were used with a layering technique in order to achieve the aesthetic results of the restorations. Regarding posterior teeth, they were included in the study when showing 2 or 3 remaining coronal walls. The restorative procedure was carried out using a centripetal technique (Hassan et al 1987, Bichacho 1994), and layering procedure also included opaque dentin and enamel shades.

The patients were recalled at 6, 12, 24 and 30 months for clinical and radiographic evaluation of the endodontically-treated and restored teeth. All restorations were placed between January and February 2002. The patients were recalled before the end of July 2002 for first evaluation, before February 2003 for the second evaluation, before February 2004 for the third evaluation and before August 2004 to complete the final evaluation. During the recall appointments, an assessment of the stability and longevity of the restorations was performed with the following criteria: 1. The presence or absence of periapical lesions; 2. Marginal leakage and integrity; 3. Color stability; 4. Surface staining; 5. Loss of retention due to fracture of the post or fracture of the composite build-up material. The restorations were evaluated by
two operators who 1) were not involved with the restorations, and 2) who were not revealed of the time of recall (single blind trial).

8.3 Results

Table 1 shows the recall data obtained after 1, 6, 12, 24 and 30 months.

Table 1

<table>
<thead>
<tr>
<th>Periapical lesions (n=100)</th>
<th>A Absent</th>
<th>B Present but without symptoms</th>
<th>C Present - to be retreated</th>
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<tr>
<td>Baseline</td>
<td>100 (100%)</td>
<td></td>
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<tr>
<td>1 month</td>
<td>100 (100%)</td>
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<tr>
<td>6 months recall</td>
<td>97 (97%)</td>
<td>3 (3%)</td>
<td></td>
</tr>
<tr>
<td>12 months recall</td>
<td>97 (97%)</td>
<td>3 (3%)</td>
<td></td>
</tr>
<tr>
<td>24 months recall</td>
<td>96 (96%)</td>
<td>3 (3%)</td>
<td>1 (1%)</td>
</tr>
<tr>
<td>30 months recall</td>
<td>96 (96%)</td>
<td>3 (3%)</td>
<td>1 (1%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Retention (n=100)</th>
<th>Present</th>
<th>Partial loss</th>
<th>Complete loss</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>100 (100%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 month</td>
<td>100 (100%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 months recall</td>
<td>97 (97%)</td>
<td>3 (3%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 months recall</td>
<td>96 (91%)</td>
<td>4 (9%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>24 months recall</td>
<td>95 (95%)</td>
<td>5 (5%)</td>
<td></td>
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<tr>
<td>30 months recall</td>
<td>95 (95%)</td>
<td>5 (5%)</td>
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<table>
<thead>
<tr>
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<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
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<td>Baseline</td>
<td>100 (100%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 month</td>
<td>100 (100%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 months recall</td>
<td>98 (98%)</td>
<td>2 (2%)</td>
<td></td>
</tr>
<tr>
<td>12 months recall</td>
<td>96 (96%)</td>
<td>4 (4%)</td>
<td></td>
</tr>
<tr>
<td>24 months recall</td>
<td>95 (95%)</td>
<td>5 (5%)</td>
<td></td>
</tr>
<tr>
<td>30 months recall</td>
<td>94 (95%)</td>
<td>6 (6%)</td>
<td></td>
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</tbody>
</table>

Legends: A= excellent continuity at the restorative-tooth interface, no discoloration; B= Slight discoloration at the interface; C= Moderate discoloration at the restorative-tooth interface measuring 1 mm or greater or recurrent decay at margins, and need for replacement.

Color stability (n=100)

<table>
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<tr>
<th>A</th>
<th>B</th>
<th>C</th>
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</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>100 (100 %)</td>
<td></td>
</tr>
<tr>
<td>1 month</td>
<td>100 (100 %)</td>
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</tr>
<tr>
<td>6 months recall</td>
<td>98 (98%)</td>
<td>2(2%)</td>
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<tr>
<td>12 months recall</td>
<td>97 (97%)</td>
<td>3(3%)</td>
</tr>
<tr>
<td>24 months recall</td>
<td>96 (96%)</td>
<td>4(4%)</td>
</tr>
</tbody>
</table>

Legends: a) No mismatch; b) Slight discoloration not requiring replacement; c) Discoloration requiring replacement

Surface staining (n=100)

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
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<tbody>
<tr>
<td>Baseline</td>
<td>100 (100 %)</td>
</tr>
<tr>
<td>1 month</td>
<td>100 (100 %)</td>
</tr>
<tr>
<td>6 months recall</td>
<td>97 (97%)</td>
</tr>
<tr>
<td>12 months recall</td>
<td>94 (94%)</td>
</tr>
<tr>
<td>24 months recall</td>
<td>93 (93%)</td>
</tr>
<tr>
<td>30 months recall</td>
<td>92 (92%)</td>
</tr>
</tbody>
</table>

Legends: a) Absent; b) Present.
At 1- or 2-year recall, endodontic retreatment was performed on those patients with persisting periapical lesions, and/or clinical symptoms. Only 4 teeth exhibited periapical lesions after 30 months of clinical service, and in one case retreatment was performed without replacing the direct restoration. After 30 months 5 out of 100 teeth showed a partial loss of the restoration. This was manifested as “chipping” of the resin composite. The restorations were repaired using the same resin composite used for the initial restoration. Six out of the hundred teeth examined exhibited slight marginal staining. They were also successfully refurbished using the same material used for the initial restoration. After 2 years of clinical service, only 4 teeth showed a slight discoloration, not requiring replacement. Surface staining was present in 8 out of 100 teeth after 2 years of clinical service. These teeth were finished and polished.

Representative results are demonstrated with the following two clinical cases:

CLINICAL CASE #1

This 21 years old patient was treated as an emergency case after a car accident (fig 1a). Tooth 11 was asymptomatic apart from the enamel and dentin fracture, and was restored with a direct resin restoration. The left central incisor (tooth 11) had an irreversible pulp injury and was endodontically-treated. After root canal treatment, a fiber post was inserted (fig 1b). Then the restoration was completed with the same resin composite material used to restore tooth 11 (fig 1c). During the recall appointment, the patient did not want to prepare tooth 11 for a full ceramic crown for economic reason. The restorations were refurbished with BisCover (Bisco), a composite surface sealant and the clinical and radiographic result after 30 months are illustrated in fig. 1d and 1e.

CLINICAL CASE #2

This 53 years old patient was initially examined for an acute pain regarding tooth 44. The premolar was subsequently endodontically-treated (fig2a), and a direct resin composite restoration was placed after the bonding of a fiber post to the root-treated tooth (figs 2b,2c). An all ceramic crown was suggested as a treatment alternative to the patient. However, for economic reasons, the patient decided to postpone the indirect restoration. Figs 2d and 2e show the clinical and radiographic results of the composite restoration after 30 months.
8.4 Discussion

In the last decade, metallic posts have been widely used for restoring endodontically-treated teeth. Metal posts (i.e., alloys or titanium) were most commonly used because of their physical properties (Sorensen et al 1984): their high stiffness and rigidity were highly appreciated. Because of their color, they cannot meet the aesthetic demands of contemporary direct resin composite restorations. The aesthetic requirements for posts and cores became even more demanding following the introduction of more translucent, enamel-like all-porcelain restorations. Some authors have emphasized the need to use endodontic posts made with biomechanical properties similar to those of dentin. Fiber posts are the only available materials that have this property (Ferrari et al 2002). This is because the stresses that were distributed to the residual tooth structure by the presence of a metal post were much higher than when a fiber-post was used (Ausiello et al 1997, Yamada et al 2004). The important difference between using "stiff" metal posts and flexible resin based posts is in the transfer of stress (energy) from restoration to tooth. With flexible posts all stress is located at the top of the root (the root-crown border area) while the stiff post can transfer stress down in the root canal.

The rapid influx of these new aesthetic fiber posts has imposed the need for a systematic evaluation of their mechanical properties and clinical performances. For that purpose, scanning electron microscopy (SEM) –with or without the use of a tracer- (Ferrari et al 2001a, Tay et al 1995), transmission electron microscopy (TEM) and fatigue test (Baran et al 2001) can provide an indication of the type of post that would perform better under clinical conditions. The evaluation of the efficacy of adhesive systems used for bonding of fiber posts may be performed by observing the uniformity of the resin-dentin interdiffusion zone (RDIZ), resin tags, and adhesive lateral branches (Drummond et al 1999), and by recording the presence of voids/bubbles within the luting material or at the interface between the cavity wall and the post (Ferrari et al 2001b).

In this clinical trial, microbrushes were used to carry the “one-bottle” adhesive system inside the root canal. The importance of the microbrush in reaching the narrowest and deepest portions of the root canal preparations has been shown by recent findings (Ferrari et al 2001b, Vichi et al 2002). The microbrush is also able to
reach all the prepared root canal dentin, resulting in a deep diffusion of resin into the
tubes and in the formation of lateral branches (Nakabayashi et al 1998, Chappel et
al 1994).

The results of this clinical trial can be important in that direct resin restorations were
performed, whereas previous prospective and retrospective studies evaluated fiber
post/resin restorations that were covered with either full porcelain or metal-ceramic
crowns (Fredriksson et al 1998, Ferrari et al 2000a and 2000b, Monticelli et al
2003). Thus, we were able to analyze the clinical performances of fiber post and
resin restoration alone. Moreover, the preservation of tooth structure is regarded as
the most important aspect in increasing the survival rate of endodontically-treated
procedures and direct resin composites are used, all the tooth structure remaining
after caries removal and the root canal treatment is preserved. On the contrary, tooth
preparation for an indirect restoration would eliminate a substantial amount of sound
tooth structure. A 2.5 years period of observation is short, for this reason the
evaluation is being continued to have more significant clinical results.

After 30 months, good coronal seals were achieved with the direct resin composites
and fiber post restorations, as the incidence of persistent periapical lesions did not
differ from those provided by other studies (Fredriksson et al 1998, Ferrari et al
2000a and 2000b, Monticelli et al 2003). In the only case that was endodontically
retreated, the procedure was performed without removing the direct restoration. The
composite material was partially removed until the fiber post was visible. Then the
removal of the post was performed using a “removal kit” provided by the
manufacturer (Removal Kit, RTD, France). After the completion of the new
endodontic procedure, a new post was inserted and the restoration completed with
resin composite. The whole procedure of the endodontic retreatment was easily
performed, according to recent data available in the literature (Gesi et al 2003).

Marginal discoloration, and “chipping” of the resin material sometimes occurred,
and their repair with the same type of composite achieved acceptable clinical results
(Frankemberger et al 2003, Saunders 1990). In 8 out of 100 cases, slight
discoloration of the restorations were present after 30 months. Refurbishing and
polishing were performed, and these procedures appeared to have prevented further
discoloration or color mismatch problems. Undoubtedly, the resin composite employed is inferior in terms of wear resistance (Yip et al 2004), when compared to full ceramic or ceramometal crowns (Derand et al 1999). On the other hand, porcelain are susceptible to brittle failure, while ductile materials utilize their plasticity to reduce stress concentrations along the crack tip (Derand et al 1999). The use of a direct resin restoration is also more economical from the patient’s point of view, as these restorations are much cheaper than any other indirect restorations. The use of direct composite restorations also minimizes the amount of residual tooth structure that has to be sacrificed for full crown coverage. They are also less time consuming in their fabrication and no additional laboratory costs are required. The ability to refurbish these fiber post-direct composite restorations is thus an important alternative with the potential to save tooth structure and increase the longevity of restorations at a lower cost (Hickel et al 2004, Mjor et al 2002). In cases with questionable prognosis, it is also desirable to wait for a period of time before making definitive indirect restorations.

It has recently been shown that if a quality fiber post with good mechanical properties is used, it can resist up to two million cycles in fatigue testing (Grandini S, Goracci C, Monticelli F, Tay FR, Ferrari M. Fatigue resistance and structural characteristics of fiber posts: three-point bending test and SEM evaluation. Dent Mater-in press). It is encouraging to observe that no post or root fracture occurred after 30 months of clinical service, confirming the results of previous studies (Fredriksson et al 1998, Ferrari et al 2000a and 2000b). Longer clinical trials should be performed to validate the use of fiber posts and direct resin composites as a simplified conservative approach to the rehabilitation of endodontically-treated teeth.

8.5 Conclusions
After 30 months of clinical service, the root canal treated teeth restored with fiber posts and direct resin composite restorations exhibited favourable clinical results.
References


Chapter 9    Summary and conclusions

It has always been a big challenge for clinicians to restore endodontically-treated teeth. Fiber posts acquired high importance in this field in the last 15 years. This thesis contains a study about several different basic and clinical aspects related to the selection and use of fiber posts.

There is scientific evidence showing that a healthy tooth is different from an endodontically-treated tooth. Many changes can occur after root canal treatment in terms of the physical, chemical and elastic properties of dentin, resistance to fatigue, morphology and biomechanical behavior. A vital tooth presents with a stiffer structure (enamel) and a more compliant support underlying it (dentin). Caries and tooth preparation for endodontic treatment are the first factors that can reduce tooth resistance. There is a decrease in moisture content (Helfer et al. 1972), an increased Young’s modulus (Huang et al. 1992), and a reduction in the percentage of collagen fibrils in dentin (Mason 2001, Hashimoto et al. 2000, Ferrari et al. 2004). Moreover, changes also occur in the morphology and in the biomechanical behavior of teeth under stress (Grimaldi 1971, Tidmarsh 1976). The access preparation for endodontic treatment causes the loss of both the roof of the pulp chamber and the marginal ridges, influencing the relatively high fracture incidence documented in maxillary premolars (Ross et al. 1980, Salis et al. 1987). In general, removal of the roof of the pulp chamber, together with endodontic procedures, are responsible for a reduction in the fracture resistance (Fuzzi 1993, Morgano et al. 1993, Trabert et al. 1978, Milot et al. 1992).

It is also known that the likelihood of survival of a pulpless tooth is directly related to the quantity and quality of remaining tooth structure (Assif et al. 1994, Gutman 1992, Cohen et al. 1996). Traditionally, a post was inserted to ensure retention of the core and to “reinforce” the tooth. To date, the eventual reinforcement provided by metal posts is no longer considered as possible (Shillimburg HT 1997), as they “…do not significantly strengthen endodontically-treated teeth…” (Sorensen 1984a). The progress made in the technology of fiber-reinforced materials have improved the structure, shape, and optical properties of contemporary fiber-reinforced resin posts. This led to the development of materials which have
overcome some of the limitations of metallic posts (platinum, alloys or titanium), concerning esthetic appearance, mode of failure, and clinical performance. In terms of esthetics, translucent fiber posts were introduced commercially to support anterior restorations (Vichi et al. 2000a and 2000b, Ferrari et al. 2001a and 2001b, Ferrari et al. 2002, Paul et al. 1998, Heydecke et al. 2002). As far as the mechanical behavior and failure mechanisms of fiber posts are concerned, it has been shown that metallic posts on failure tend to produce irreversible root fractures. Conversely, root fracture that occur with the use of fiber posts are usually located more coronally and are more easily retreatable (Akkayan et al. 2002, Cornier et al. 2001, Reagan et al. 1999, Newman et al. 2003). This type of failure may be due to the greater amount of tooth structure that must be removed when a metallic post is placed (Stankiewitz et al. 2002). In the event that endodontic re-treatment is necessary, fiber posts are more easily removed than either metallic or ceramic ones (Gesi et al. 2003, Hauman et al. 2003). In conclusion, fiber posts function well as retention for resin composite cores. When compared to metal or zirconia posts, they are able to preserve residual tooth structure due to their mechanical behavior and the accompanying luting procedures.

Techniques has been described for restoring endodontically-treated teeth with the use of resin composites to replace lost root dentin, with the possibility of strengthening the root. Unfortunately these reports were published in non peer-reviewed publications (Freedman et al. 1994, Godder et al. 1994, Martelli 2000, Castellucci 2004). A recent study was performed comparing the fracture resistance and failure patterns of endodontically-treated maxillary premolars with a progressively reduced number of residual walls, that were restored using resin composite materials with or without translucent glass fiber posts (Sorrentino et al. 2004). This study showed that the number of residual dental walls influenced the mechanical resistance of endodontically-treated maxillary premolars. In specimens with the same number of residual dental walls, higher fracture loads were recorded in teeth restored with fiber posts. Moreover, restorable fractures were observed in the specimens restored with fiber posts. If these data can be subsequently validated with clinical studies, the concept of reinforcing root structures with the bonding of fiber posts to root canals will be more firmly established.
A successful endodontic procedure is a key factor to ensure success in the restoration of root-treated teeth. A well performed endodontic treatment is based on the removal of debris and organic material inside the root canal (Castellucci 1993) and on the mechanical preparation of the canal itself to receive an obturation material (Ingle 1993). The influence of cements and irrigating solutions has been extensively discussed in the literature. When evaluating the effect of different irrigating regimes on the cleanliness of the root canals achieved after endodontic treatment (Grandini et al. 2002b), it was found that none of the techniques used in that study showed a perfect removal of the smear layer and debris. However, it was noted that a combination of sodium hypochlorite and a chelating agent can help reduce the amount of debris along root canal walls. The functions of root canal filling are essentially to seal the root canal and to prevent further microleakage. In this sense, post fabrication and placement can be considered as part of the endodontic treatment if they contribute to the filling and sealing of the root canal space (Trope 2004). Unfortunately, due to the high C-factors encountered in post spaces (Morris et al., 2002; Bouillaguet et al., 2003; Goracci et al., 2004), substantial difficulty was experienced with the luting of fiber posts to intraradicular dentin with resin cements. It has been suggested that similar to the use of non-bonding cements, a substantial part of the dislocation resistance of bonded fiber posts to root canals is contributed by sliding friction (Goracci et al., 2005).

The popularity with the use of fiber posts for restoration of the endodontically-treated teeth has imposed the need for a systematic evaluation of the different brands and types of fiber posts available commercially. Some criteria are usually employed, such as the composition and shape of the post, cost and luting procedures, based on basic and experimental evaluations. A study comparing the fatigue resistance and the structural characteristics of different types of fiber posts has been described (Grandini et al. 2004a). Some brands of fiber posts can resist up to 2,000,000 cycles of fatigue testing without affecting their general quality. In particular the quality of the bonding between the two components of a fiber post (the fibers and the epoxy resin matrix) can influence the quality of the post itself. As a matter of fact, static impact and fatigue properties are proportional to the strength of the filler/resin interface in fiber-reinforced composite systems (Zhao et al. 2000, Kessler et al.
A recent study confirmed that increasing the strength of the bond between the fillers and matrix will result in improvements in the mechanical properties of fiber-reinforced composites (Debnath et al. 2004). Luting procedures are extremely important as far as fiber posts are concerned. The recommended procedure has already been described in the literature (Ferrari et al. 2001a and 2001b, Vichi et al. 2002a). Acid etching, the use of a fourth or fifth generation adhesive, and of a dual-curing resin cement provides the best clinical results. Leaving the adhesive solution unpolymerized before placing the cement (one-step procedure), in order to reduce the time for the cementation procedure, produces unfavourable results both from the clinical and experimental standpoint (Grandini et al. 2004b). If a crown is placed, the post can be adjusted after the core restoration. In case a direct restoration is placed, it is better to adjust the length of the post before the luting procedures. The adjustment should be performed with a carborundum disk or a diamond bur (Grandini et al. 2002a). This way, it is possible to cover the cut end of the post with resin composite, a material much more able than a fiber post to resist tooth-to-tooth and tooth-to-food wear. If a post is good enough, cutting procedures will not affect its structural integrity.

Much development occurred concerning the materials used for the fabrication of posts: carbon was the first material employed; glass, quartz and silica have subsequently been used, taking advantage of their translucent optical properties. Interesting development was also seen in the modification of the design of these posts, from the original double-cylinder, endodontic shapes, to the more recently introduced double-tapered shapes, as adhesive cementation now relies more on the formation of the resin-dentin interdiffusion zone and resin tags rather than on the good fitting and mechanical retention of the post inside the root canal (Ferrari et al. 2002). Moreover, a wider selection of sizes permits conservation of the amount of residual dentin that has to be removed in order to achieve a satisfactory post adaptation. Debonding is more likely to occur in the absence of the desirable ‘ferrule effect’, or in the presence of an overly thick layer of cement wherein the entrapment of bubbles is conducive to debonding (Ferrari et al. 2000a). The idea of having a custom-fabricated post that fits individual post space is appealing, especially when dealing with root canals that have elliptical shapes, such as those observed in
canines and lower premolars. In these cases, the clinician is forced to adapt the residual root structure to the post shape, through the removal of a further amount of dentin. On the contrary, it would be desirable that the post adapt to the root canal anatomy as produced by the endodontic treatment. This is indeed the rationale for the creation of an anatomic post (Grandini et al 2000, Boudrias et al. 2001a and 2001b). Recently the Anatomic Post’n Core (RTD, St Egrève, France) has been introduced (Ferrari et al. 2002). This new post is made by a DT post n. 1 that is covered by a light-curing resin (Lumiglass, RTD, St Egrève, France). The refining resin is able, once introduced in the root canal, to produce a good fitting thus reducing the amount of cement to be used and stabilizing the post during the luting procedures.

The final test for a clinical procedure is always the clinical evaluation. Many studies reported on the use of fiber post to restore endodontically-treated teeth (Malferrari et al. 2003, Ferrari et al. 2000a and 2000b, Fredriksson et al. 1998, Monticelli et al. 2003, Dallari et al. 1998, Scotti et al. 2002). The majority of them combines the use of fiber post restorations with ceramic or ceramometal crowns. The last few years have seen an enormous expansion in the indications for direct resin composite restorations (Hickel et al. 2004). Thus, it is interesting to evaluate the performances of fiber posts when they were used in conjunction with direct resin restorations, without additional crown coverage. After 30 months of clinical service, root-treated teeth restored with fiber posts and direct resin composite restorations exhibited no root fractures and favourable clinical results.

Conclusions and recommendations
The following conclusions and recommendations may be drawn from our basic and clinical evaluations on the use of fiber posts in dentistry:
1) Fiber posts exhibit good overall mechanical properties and the related failure modes are usually more conservative and favorable when compared to metallic posts.
2) Endodontic procedures can influence the final result of the post restoration. Great attention should be placed in the removal of bacteria, debris and other materials inside the root canal before the filling is completed.
3) Fiber posts contribute to the filling sealing of the root canal space with the help of adhesive cementation. For this reason they can be considered as part of the endodontic treatment.

4) There are several brands of fiber posts. The quality of the bonding between the fibers and the resin may influence the final quality of the whole post, and this should be taken into account when selecting a fiber post together with composition, desired shape, basic and experimental evaluation.

5) As far as luting procedures are concerned, a reliable bonding between the fiber post-resin cement unit and the root canal can be reasonably well achieved with the use of acid etching, that has to removed meticulously from the root canal with a syringe and an endodontic needle.

6) A fourth or fifth generation adhesive system, inserted in the canal with the help of a microbrush, and a dual-curing resin cement can be recommended when using translucent fiber posts.

7) An individual post (Anatomic Post’n Core) can be of great help in a clinical situation where there is a great loss of coronal structure and root canals after endodontic treatment end up in a non-rounded shape.

8) Fiber posts can be safely used in combination with ceramic or ceramo-metal crowns. Indications for their use are rapidly expanding, and recent clinical studies indicated that they can be safely used as a foundation for direct resin composite crowns. With the use of this technique, the restoration of the endodontically treated teeth can be easier and less costly.
Riassunto e conclusioni

Il restauro del dente trattato endodonticamente ha da sempre rappresentato una grossa sfida, e negli ultimi 15 anni i perni in fibra hanno acquisito una grossa importanza in questo campo. Questa tesi contiene uno studio riguardante diversi aspetti scientifici di base e clinici in relazione all’uso dei perni in fibra.


La possibilità di sopravvivenza nel cavo orale di un dente trattato endodonticamente è direttamente proporzionale alla qualità ed alla quantità della struttura dentale residua (Assif et al. 1994, Guttman 1992, Cohen et al. 1996). Tradizionalmente, veniva inserito un perno per assicurare ritenzione alla ricostruzione coronale e per “rinforzare” il dente. Attualmente, l’eventuale rinforzo determinato da un perno metallico non può più essere considerato possibile (Shillimburg HT 1997), poiché esso “...non rinforza significativamente il dente trattato endodonticamente...”

Sono state riportate tecniche cliniche per il restauro del dente trattato endodonticamente con resine composite per ripristinare la struttura dentale residua e per rinforzare la radice. Sfortunatamente questi report sono stati pubblicati su riviste prive di revisione da parte di esperti (Freedman et al. 1994, Godder et al. 1994, Martelli 2000, Castellucci 2004).

Uno studio recente ha comparato la resistenza alla frattura e le modalità di fallimento di premolari superiori trattati endodonticamente con un numero progressivo sempre minore di pareti residue, che sono state ricostruite usando resine composite con o senza perni in fibra translucenti (Sorrentino et al. 2004). Questo modello di studio ha mostrato che il numero di pareti residue influenza la resistenza
meccanica dei denti sottoposti a carico: in campioni con lo stesso numero di pareti residue sono state registrati valori più elevati di resistenza alla frattura nei denti “rinforzati” con perni in fibra. Inoltre, nei campioni ricostruiti con i perni in fibra le fratture osservate erano “favorevoli”, quindi fratture facilmente riparabili in quanto avvenute al di sopra della cresta ossea. Se questi dati dovessero essere confermati da studi clinici, il concetto di “rinforzare” le strutture radicolari con l’adesione al canale di perni in fibra sarà indiscutibilmente rafforzato.

Un trattamento endodontico efficace risulta essere un fattore chiave nell’ambito del restauro del dente trattato endodonticamente. Di basilare importanza risultano la rimozione di detriti e materiale organico dall’interno del canale (Castellucci 1993) e la preparazione meccanica del canale stesso per ricevere un materiale da otturazione (Ingle 1993). L’influenza dei cementi e delle soluzioni irriganti è stata discussa ampiamente in letteratura. Valutando l’effetto di diverse soluzioni irriganti nell’ottenere un canale libero da impurità dopo il trattamento endodontico (Grandini et al. 2002b), si è verificato che nessuna delle tecniche usate nello studio in oggetto si è dimostrata perfettamente efficace nel rimuovere completamente fango dentinale e detriti. Ad ogni modo, una combinazione di ipoclorito di sodio e di un agente chelante possono efficacemente rimuovere gran parte dei detriti dal canale. Gli scopi dell’otturazione canaleare sono essenzialmente quelli di sigillare il canale radicolare e prevenire l’ulteriore eventuale microinfiltrazione. In questo senso, il posizionamento di un perno in fibra può aiutare a fornire un sigillo efficace contro l’infiltrazione batterica coronale (Trope 2004). Sfortunatamente, a causa dell’elevato fattore C presente nei canali radicolari (Morris et al., 2002; Bouillaguet et al., 2003; Goracci et al., 2004), sono state registrate difficoltà nella cementazione dei perni in fibra alla dentina intra-radicolare con i cementi resinosi. Si è speculato che, come per l’uso di cementi non adesivi, una elevata quota parte della resistenza alla dislocazione incontrata nei perni in fibra cementati adesivamente sia data dal contributo della frizione da contatto del perno stesso e del cemento resinoso all’interno del canale radicolare (Goracci et al., 2005).

La sempre maggiore popularità incontrata dai restauri con perni in fibra ha imposto la necessità di una valutazione sistematica dei diversi tipi e qualità dei perni in fibra ad oggi presenti sul mercato. I criteri di scelta sono generalmente basati sulla
composizione e forma dei perni, costo, procedure di cementazioni adesive, valutazioni sperimentali in vivo e in vitro. Uno studio ha comparato la resistenza alla fatica e le caratteristiche strutturali di diversi tipi di perni in fibra (Grandini et al. 2004a). Alcuni tipi di perni in fibra possono facilmente resistere fino a 2.000.000 di cicli di fatica senza cambiamenti alla loro struttura. In particolare, la qualità dell’adesione e del legame fra le due componenti del perno in fibra (le fibre e la matrice di resina epoxidica) può influenzare la qualità del perno stesso. Infatti, l’impatto statico e la resistenza alla fatica sono proporzionali alla forza di adesione dell’interfaccia riempitivo/resina nei sistemi compositi rinforzati con fibre (Zhao et al. 2000, Kessler et al. 2000, Keusch et al. 1999). Uno studio recente ha confermato che all’aumentare della forza di adesione tra il riempitivo e la matrice si ottiene un incremento delle proprietà meccaniche dei compositi rinforzati con fibre (Debnath et al. 2004).

Le procedure di cementazione sono un fattore estremamente importante nell’ambito del restauro con perni in fibra, e sono da tempo state descritte nella letteratura internazionale (Ferrari et al. 2001a and 2001b, Vichi et al. 2002a). La mordenzatura acida, l’uso di adesivi di quarta o quinta generazione, e di un cemento resinoso duale porta a risultati clinici ottimali. Il fatto di lasciare la soluzione adesiva non polimerizzata prima del posizionamento del cemento (one-step procedure), allo scopo di ridurre il tempo necessario per la cementazione, produce risultati clinici sfavorevoli sia dal punto di vista clinico che sperimentale (Grandini et al. 2004b).

Nel caso si scelga di eseguire una corona dopo il posizionamento del perno in fibra, il perno stesso può essere aggiustato in lunghezza dopo il restauro del core. Invece, nel caso in cui si sceglia un restauro conservativo, è preferibile aggiustare la lunghezza del perno prima di procedere alla cementazione, in modo da poter eseguire al contempo cementazione del perno e ricostruzione adesiva avvalendosi di un’unica fase di mordenzatura ed adesione. Il taglio del perno può avvenire con un disco di carborundum o con una fresa diamantata (Grandini et al. 2002a). In questo modo è possibile ricoprire la testa del perno con resina composta, un materiale cioè maggiormente capace di resistere alle sollecitazioni dell’usura dente contro dente e dente contro cibo. Se siamo di fronte ad un perno di buona qualità, la procedura di taglio non modificherà l’integrità strutturale del perno stesso.
Negli anni molti cambiamenti hanno riguardato i materiali impiegati per la fabbricazione dei perni in fibra: il carbonio è stato il primo materiale impiegato; quindi il vetro, il quarzo e la silice, con particolare riguardo alle capacità di trasmissione della luce. Interessanti sviluppi hanno inoltre riguardato la forma dei perni stessi, partendo dal doppio cilindro originale, fino alle forme endodontiche ed ai più recenti perni a doppia conicità. Infatti la cementazione adesiva permette di affidarsi alla formazione di zaffir resinosi e strato ibrido piuttosto che alla forma ritentiva, alla ritenzione meccanica ed al perfetto adattamento del perno all’interno delle pareti canalari (Ferrari et al. 2002). Inoltre, nel conseguire l’adattamento del perno, una maggiore varietà di perni disponibili sul mercato permette all’operatore di selezionare quello più appropriato allo scopo di risparmiare la maggior quantità di struttura dentale residua. La decementazione avviene più facilmente in assenza dell’auspicabile “effetto ferula”, o in presenza di un elevato spessore di cemento nel quale è più verosimile che si verifichi l’intrappolamento di bolle d’aria che può portare appunto alla decementazione (Ferrari et al. 2000a). L’idea di avere un perno individuale, che si adatti perfettamente al singolo spazio canalare è decisamente attraente per l’operatore, specialmente quando si tratti di canali con forma ellittica così come i canini ed i premolari. In questi casi il clinico è costretto ad adattare la struttura dentale residua al perno attraverso la rimozione di un’ulteriore quantità di dentina, o a cementare un perno affidandosi ad una maggiore quantità e spessore di cemento. Al contrario, sarebbe desiderabile che il perno si adattasse all’anatomia canalare prodotta dal trattamento endodontico. Questo è infatti il fondamento logico alla base della creazione del perno anatomico (Grandini et al 2000, Boudrias et al. 2001a and 2001b). Recentemente è stato introdotto l’ Anatomic Post’n Core (RTD, St Egrève, France) (Ferrari et al. 2002). Questo nuovo perno è composto da un perno a doppia conicità (DT) numero 1, ricoperto da una resina foto-polimerizzabile (Lumiglass, RTD, St Egrève, France). La resina ribasante è in grado, una volta introdotta nel canale, di produrre un buon fitting fra perno ribassato e pareti canaliari, riducendo la quantità di cemento e stabilizzando il perno durante le procedure di cementazione.

Ma il test decisivo e finale per una procedura è sempre la valutazione clinica. Molti studi presenti in letteratura hanno riguardato l’uso dei perni in fibra per il restauro

Conclusioni e raccomandazioni
Sulla base delle valutazioni cliniche e sperimentali possiamo trarre le seguenti conclusioni e raccomandazioni riguardo l’uso dei perni in fibra in odontoiatria.

1) I perni in fibra hanno mostrato buone proprietà meccaniche ed il relativo modo di fallimento è generalmente più conservativo e favorevole di quello mostrato dai perni metallici.

2) Le procedure endodontiche possono influenzare il risultato finale del restauro con perno. Deve essere posta grande attenzione nella rimozione di batteri, detriti ed altri materiali dall’interno del canale prima di procedere all’otturazione canalare.

3) I perni in fibra possono contribuire al sigillo dello spazio canalare con l’aiuto della cementazione a desiva. Per questa ragione possono essere considerati come parte del trattamento endodontico.

4) Ci sono diversi tipi di perni in fibra. La qualità del legame tra le fibre e la matrice può influenzare la qualità globale del perno, e questo dovrebbe essere preso in considerazione al momento della scelta del perno, insieme alla composizione, alla forma, ed alla valutazione di base e clinica.

5) Per quanto riguarda le procedure di cementazione, un legame affidabile fra perno in fibra, cemento, sistema adesivo e canale radicolare può essere raggiunto con la mordenzatura acida. Il mordenzante deve essere accuratamente rimosso dal canale radicolare con una siringa contenente acqua ed un ago endodontico.
6) Un sistema adesivo di quarta o di quinta generazione, veicolato nel canale con l’aiuto di un microbrush, ed un cemento resinoso duale possono essere adoperati con i perni in fibra translucenti.

7) Un perno individuale (Anatomic Post’n Core) può essere di grande aiuto in situazioni cliniche dove si abbia grossa perdita di struttura coronale ed un canale che risulta non circolare dopo il trattamento endodontico.

8) I perni in fibra possono essere adoperati con sicurezza in combinazione con restauri protesici in ceramica o in metallo-ceramica. Le indicazioni per il loro uso sono in rapida espansione, e studi clinici recenti indicano che possono essere adoperati anche come base per un restauro diretto in resina composita. Con questa tecnica, il restauro del dente trattato endodonticamente può essere più semplice e più economico.
Résumé et conclusions


La possibilité de survie dans la cavité orale d’une dent traitée endodontiquement est directement proportionnelle à la qualité et à la quantité de la structure dentaire restante (Assif et al. 1994, Guttmann 1992, Cohen et al. 1996). Traditionnellement, un tenon était mis en place pour assurer la rétention à la reconstruction coronaire et pour renforcer la dent. Actuellement, l’éventuelle consolidation déterminée par un tenon métallique ne peut plus être considérée possible (Shillimburg HT 1997),
Une étude récente a comparé la résistance à la fracture et les modalités de faillite de prémolaires supérieures traitées endodontiquement avec un nombre progressif toujours plus petite de parois restantes, qui ont été reconstruites avec des résines
composites avec ou sans tenons en fibres translucides (Sorrentino et al. 2004). Ce modèle d’étude a démontré que le nombre de parois restantes influence directement la résistance mécaniques des dents soumises à une charge. Des échantillons avec le même nombre de parois restantes ont permis d’enregistrer des valeurs plus élevées de résistance à la fracture dans les dents « renforcées » avec des tenons en fibres. De plus, dans les échantillons reconstruits avec les tenons en fibres, les fractures observées étaient « favorables », c'est-à-dire des fractures facilement réparables car elles s’étaient produites au dessus de la crête osseuse. Si ces données peuvent être confirmées par des études cliniques, l’idée de « renforcer » les structures radiculaires avec le collage canalaire des tenons en fibres sera sans aucun doute renforcé.

Un traitement endodontique efficace se révèle être un facteur clef dans les limites de la restauration de la dent traitée endodontiquement. Un traitement performant est basé sur l’enlèvement de débris et de matière organique de l’intérieure du canal (Castellucci 1993) et la préparation mécanique de ce canal pour recevoir un matériau d’obturation (Ingle 1993). L’influence des ciments et des solutions irrigantes a été amplement discutée en littérature. D’après l’évaluation de l’effet de différentes solutions irrigantes dans le but d’obtenir un canal exempt d’impuretés après le traitement endodontique (Grandini et al. 2002b), il a été vérifié qu’aucune des techniques employées dans l’étude ne s’est montrée parfaitement efficace pour enlever complètement la boue et les détritus. Cependant, une combinaison d’hypochlorite de sodium et d’un agent chélatant peut efficacement enlever une grande partie des détritus du canal. Les fonctions de l’obturation canalaire sont essentiellement de sceller le canal radiculaire et de prévenir une éventuelle micro infiltration ultérieure. Dans ce sens, le placement d’un tenon en fibres peut aider à fournir un sceau efficace contre l’infiltration bactérienne coronaire (Trope 2004). Malheureusement, à cause de « facteur C » élevé présente dans les canaux radiculaires (Morris et al., 2002; Bouillaguet et al., 2003; Goracci et al., 2004), on a enregistré des difficultés dans le scellement des tenons en fibres à la dentine intra radiculaire avec les ciments résineux. On croit que, comme pour l’emploi de ciments non adhésifs, une résistance au dé-scellement rencontré dans les tenons en fibres cimentés adhésivement est donnée par la friction du contact tenon-ciment résineux à l’intérieur du canal radiculaire (Goracci et al., 2005).
La popularité toujours croissante rencontrée par les restaurations avec les tenons en fibres a imposé la nécessité d’une évaluation systématique des différents types et de la qualité des tenons en fibre aujourd’hui présents sur le marché. Les critères de choix en général sont fondés sur la composition et la forme des tenons, les coûts, sur les procédures de scellement adhésif, les évaluations expérimentales in vivo et in vitro. Une étude a comparé la résistance à la fatigue et les caractéristiques structurales de différents types de tenons en fibre (Grandini et al. 2004a). Quelques types de tenons en fibres peuvent facilement résister jusqu’à 2.000.000 de cycles de fatigue sans aucune conséquence à leur qualité générale. En particulier, la qualité de l’adhésion et du lien entre les deux composants du tenon en fibre (les fibres et la matrice de résine époxydique) peut influencer la qualité du tenon lui-même. En effet, la résistance à la charge statique et la résistance à la fatigue, sont proportionnelles à la force d’adhésion de l’interface charges-résine, dans les systèmes composites renforcés avec des fibres (Zhao et al. 2000, Kessler et al. 2000, Keusch et al. 1999). Une étude récente a confirmé que l’augmentation de la force de adhésion entre les charges (fibres) et la matrice conduit à un accroissement des propriétés mécaniques des composites renforcés avec des fibres (Debnath et al. 2004).

Les procédures de collage/scellement sont un facteur extrêmement important dans le domaine de la restauration avec des tenons en fibres, et elles ont été depuis longtemps décrites dans la littérature internationale (Ferrari et al. 2001a and 2001b, Vichi et al. 2002a). Le mordant acide, l’emploi d’adhésifs de quatrième ou cinquième génération et d’un ciment résineux dual conduit à des résultats cliniques optimales. Le fait de laisser la solution adhésive non polymérisée avant le placement du ciment (« One-Step procédure ») afin de réduire le temps nécessaire pour le scellement, conduit à des résultats cliniques défavorables tant du point de vue clinique qu’expérimental (Grandini et al. 2004b).

Le tenon peut être ajusté à la longueur adéquate après la restauration du faux-moignon dans le cas où une couronne recouvre l’ensemble. Dans le cas contraire, au cas où l’on choisit une restauration conservative, il est préférable d’ajuster la longueur du tenon avant de procéder au scellement de manière à pouvoir exécuter en même temps le scellement du tenon et la reconstruction adhésive en se servant d’une
phase unique de mordançage et de collage. La section tenon peut s’effectuer à l’aide d’un disque de carborundum ou une fraise diamantée (Grandini et al. 2002a). De cette façon il est possible de recouvrir la tête du tenon avec de la résine composite, c'est-à-dire un matériau capable de supporter les contraintes dent contre dent ou des contraintes masticatoires. Si l’on est en face d’un tenon de bonne qualité, la procédure de coupure ne modifiera pas l’intégrité de la structure du tenon.

Pendant des années beaucoup de changements ont concerné les matériaux employés pour la fabrication des tenons en fibres : les fibres de carbone ont été la première fibre employée ; après la fibre de verre, de quartz et de silice, avec une attention particulière aux capacités de transmission de la lumière. Des développements intéressants ont eu lieu sur la forme des tenons, partant du double cylindre original, jusqu’aux formes endodontiques et aux plus récents tenons à double conicité. En effet la cimentation adhésive permet de se confier à la formation de « resin tags » et à la couche hybride plutôt qu’à la rétention mécanique et à la parfait ajustement du tenon (Ferrari et al. 2002). De plus, pour obtenir l’adaptation du tenon, une plus grande variété de tenons disponibles sur le marché permet au clinicien de sélectionner le tenon le plus approprié afin d’économiser la plus grande quantité de structure dentaire restante. Le descellement survient plus facilement en l’absence du souhaitable « Ferrule effect» ou en présence d’une épaisseur élevée de ciment dans laquelle vraisemblablement des bulles d’air se sont formées conduisant au descellement (Ferrari et al. 2000a). L’idée d’avoir un tenon sur-mesure, qui s’ajuste parfaitement à chaque espace du canal est décidément attrayant pour le praticien, surtout quand il s’agit de canaux à forme elliptique telle que les dents canines et les prémolaires. Dans ces cas le clinicien est obligé d’adapter la structure dentaire restante au tenon à travers l’enlèvement d’une quantité ultérieure de dentine, ou à sceller un tenon plus petit, par conséquent d’avoir une plus grande épaisseur de ciment. Dans le cas contraire , il serait souhaitable que le tenon s’adapte à l’anatomie du canal produite par le traitement endodontique. En effet c’est le fondement logique à la création du tenon anatomique (Grandini et al 2000, Boudrias et al. 2001a and 2001b). Récemment le tenon Anatomic Post’n Core (RTD, St Egrève, France) (Ferrari et al. 2002) a été introduit. Ce nouveau tenon est composé d’un tenon à double conicité (DT) numéro 1 recouvert par un résine photo-
polymérisable (Lumiglass, RTD, St Egrève, France). La résine qui environne le tenon est à même, une fois introduite dans le canal, de produire un bon ajustement entre le tenon et le parois du canal, en réduisant la quantité de ciment et en stabilisant le tenon pendant les procédures de scellement.


Conclusions et recommandations

En ce qui concerne l’emploi des tenons en fibres en dentisterie, selon les résultats issus de nos évaluations cliniques et expérimentales, les conclusions et recommandations suivantes peuvent être comme suit :

1) Les tenons fibrés ont montré de bonnes propriétés mécaniques et le mode d’échec est en général plus favorable et conservateur que celui des tenons métalliques.

2) Les procédures endodontiques peuvent influencer le résultat final de la restauration avec le tenon. Une grande attention doit être portée à l’enlèvement de bactéries, de débris et d’autres matériaux à l’intérieur du canal avant d’obtenir le canal.

4) Plusieurs marques de tenons existent. La qualité de la liaison entre les fibres et la matrice peut influencer sur la qualité finale du tenon, et ceci devrait être pris en considération au moment du choix du tenon, en même temps que la composition, la forme, et l’évaluation de base et clinique.

5) En ce qui concerne les procédures de scellement, un lien fiable entre tenon fibré, le système adhésif et le canal radiculaire peut être atteint avec l’emploi du mordançage acide. L’acide de mordançage doit être enlevé soigneusement avec une seringue et une aiguille endodontique.

6) Un système adhésif de quatrième ou de cinquième génération, inséré dans le canal à l’aide d’un applicateur Microbrush®, et un ciment résineux duale peuvent être employé avec les tenons en fibre translucides.

7) Un tenons sur-mesure (Anatomic Post’n Core®) peut être d’une grande aide dans une situation clinique où une perte importante de substance coronaire et canalaire a conduit à une forme non circulaire après le traitement endodontique.

8) Les tenons en fibre peuvent être employés en toute sécurité en combinaison avec des restaurations prothétiques en céramique ou métallo-céramique. Les indications pour leur usage sont en constante progression, et des études cliniques récentes ont démontré qu’ils peuvent être employées aussi comme élément de base pour une restauration directe en résine composite. Avec cette technique, la restauration de la dent traitée endodontiquement peut être plus simple et plus économique.
Schlußfolgerung


Bisher wurde ein Stift eingesetzt, um den Kern zu befestigen und den Zahn zu “verstärken”. Heute ist die Verstärkung der Zahnwurzelstruktur durch Metallstifte widerlegt (Shillimburg HT 199), denn sie „...verstärken endodontisch behandelte Zähne nicht signifikant...“ (Sorensen 1984a). Im Zuge des technischen Fortschritts in

Wenn diese Daten durch klinische Studien überprüft würden, könnte die Annahme bestätigt werden, dass Wurzelkanalwände durch den Verbund mit Faserstiften verstärkt werden.


Faktors, in den Stiftpositionsräumen (Morris et al., 2002, Bouillaguet et al., 2003, Goracci et al., 2004), treten große Adhäsionsprobleme zwischen intra-radikularem Dentin und Faserstift mit Hrz-Zementen auf. Man nimmt an, dass, ähnlich wie bei nicht bindenden Zementen, auch bei den Faserstiften die Gleitfraktion im Wurzelkanal zum großen Teil dazu führt, dass der Stift sich nicht löst (Goracci et al., 2005). Da Restaurationen mit Faserstiften große Nachfrage finden, ist es notwendig, die verschiedenen Marken und Typen auf dem Markt systematisch zu untersuchen. Hierfür werden üblicherweise einige auf grundlegenden und experimentellen Untersuchungen basierende Kriterien angewandt, wie z.B. Komposition und Form des Stiftes, Kosten und Zementierungstechnik. Es gibt eine Studie die Ermüdungswiderstand und Struktureigenschaften verschiedener Faserstifte vergleicht (Grandine et al. 2004a). Einige Faserstiftmarken widerstehen ohne Qualitätsbeeinträchtigung bis zu 2.000.000 Ermüdungs-Test-Zyklen.


Was das Material der Stifte betrifft, gibt es viele Neuentwicklungen: Karbon wurde als erstes als Stiftmaterial verwendet, dann kamen Stifte aus Glas, Quarz und Silizium wegen ihrer transluzenten Eigenschaften. Im Design gab es ebenfalls interessante Entwicklungen, vom Original-Doppel-Zylinder, über endodontische Formen bis hin zu den jüngeren Double-Taper-Stiften. Hier beruht die Adhäsiv-Zementierung mehr auf die Verbindung der Harz-Marker mit dem Dentins als auf gute Passform und mechanische Verankerung des Stiftes im Kanal (Ferrari et al. 2002). Weiterhin wird durch eine erweiterte Größenauswahl der Stifte mehr Zahnsubstanz bewahrt, die für eine zufrieden stellende Stiftanpassung abgetragen


**Fazit und Empfehlungen**

Aufgrund unserer grundlegenden und klinischen Untersuchungen über die Anwendung von Faserstiften in der Zahnheilkunde können wir folgende Schlussbetrachtungen und Empfehlungen geben:
1) Im Vergleich zu Metallstiften zeigen Faserstifte allgemein positive mechanische Eigenschaften und besseres Fehlverhalten.

2) Vorangegangene endodontische Behandlungen können das Endresultat einer Stiftrestauration beeinflussen. Vor Abschluss der Füllung muss der Entfernung von Bakterien, Debris und anderen Materialien aus dem Wurzelkanal größte Beachtung beigemessen werden.


4) Es gibt mehrere Faserstiftmarken. Die Verbundqualität zwischen Faser und Harz kann die endgültige Qualität des Stiftes beeinflussen. Dies sollte, ebenso wie die Zusammensetzung, die gewünschte Form, und die grundlegenden Überlegungen bei der Wahl des Faserstiftes beachtet werden.


7) Ein individueller Stift (Anatomic Post’n Core) kann sehr hilfreich sein, wenn ein großer Verlust koronaler Struktur vorliegt, und wenn der Wurzelkanal nach endodontischer Behandlung eine nicht-runde Form aufweist.

**Resumen y conclusiones**

Siempre ha sido un desafío grande para los clínicos el restaurar dientes endodonticamente tratados. Los postes de fibra han adquirido una importancia en este campo en los últimos 15 años. Esta tesis contiene un estudio acerca de varios aspectos diferentes, básicos y clínicos relacionando la selección y el uso de postes de fibra. Existe la evidencia científica de que la actuación de un diente sano es diferente a la de un diente endodonticamente tratado. Muchos cambios pueden ocurrir después del tratamiento del canal de la raíz en términos físicos, químicos y morfológicos y de las propiedades elásticas de la dentina, la resistencia para la fatiga.

Un diente vital presenta una estructura (esmalte) más rígida y un apoyo fundamentalmente más blando (dentina). La caries y la preparación del diente para el tratamiento endodóntico son los primeros factores que pueden reducir la resistencia de un diente. Hay una disminución en el contenido de la humedad (Helfer et al. 1972), un incremento del módulo de Young (Huang et al. 1992), y una reducción en el porcentaje de fibras de colágeno en la dentina (Mason 2001, Hashimoto et al. 2000, Ferrari et al. 2004). Además, los cambios ocurren también en la morfología y en la conducta biomecánica de dientes bajo el estrés (Grimaldi 1971, Tidmarsh 1976). La preparación del acceso para el tratamiento endodóntico causa la pérdida del techo de la cámara de la pulpa y las aristas marginales, influyendo en la incidencia relativamente alta de fracturas documentadas en premolares maxilares (Ross et al. 1980, Salis et al. 1987). En general, la eliminación del techo de la cámara de la pulpa, juntos con procedimientos endodónticos, son responsables de una reducción en la resistencia a la fractura (Fuzzi 1993, Morgano et al. 1993, Trabert et al. 1978, Milot et al. 1992).

También es sabido que la probabilidad de sobrevivencia de un diente sin pulpa es relacionada directamente con la cantidad y la calidad de la estructura restante del diente (Assif et al. 1994, Guttman 1992, Cohen et al. 1996). Tradicionalmente, un poste se introducía para asegurar la retención a la recostrucción y para “reforzar” el diente. Hoy en día el refuerzo determinado por postes de metal no se puede considerar posible (Shillimburg HT 1997) porque “…no refuerza apreciablemente dientes tratados endodónticamente…” (Sorensen 1984a). El progreso hecho en la
tecnología de materiales de fibra-reforzada ha mejorado la estructura, la forma, y las propiedades ópticas de postes de fibra-reforzados de resina. Esto llevó al desarrollo de materiales que vencen algunas de las limitaciones de postes metálicos (platino, aleaciones o titanio), con respecto a la apariencia estética, el modo del fracaso y el desempeño clínico. En términos de la estética, los postes translúcidos de fibra se introdujeron para sostener comercialmente las restauraciones anteriores (Vichi et al. 2000a y 2000b, Ferrari et al. 2001a y 2001b, Ferrari et al. 2002, Paul et al. 1998, Heydecke et al. 2002). Por lo que concierne a el comportamiento bio-mecánicos y el fracaso, se ha demostrado que los postes metálicos tienden a producir fracturas irrevocables de la raíz. Opuestamente, una fractura de la raíz que ocurre con el uso de postes de fibra se localiza generalmente más coronalmente y es más fácilmente retratable (Akkayan et al. 2002, Cornier et al. 2001, Reagan et al. 1999, Newman et al. 2003). Este tipo de fracaso puede estar debido a la mayor cantidad de estructura del diente que se debe quitar cuando se coloca un poste metálico (Stankiewitz et al. 2002). En el caso en que sea necesario un re-tratamiento endodóntico, los postes de fibra son más fácilmente removibles de los metálico o los cerámicos (Gesi et al. 2003, Hauman et al. 2003). En conclusion, los postes de fibra funcionan bien como retenciones para los cementos de resinas compuestas en dientes tratados endodónticamente. Cuando se compararon con postes de metal o circonios, ellos son capaces de preservar la estructura residual del diente gracias a su conducta mecánica y a los procedimientos de cementación que los acompañan.

Se han descrito técnicas para restaurar dientes endodónticamente tratados con el uso de resinas compuestas para remplazar la dentina perdida de la raíz, con la posibilidad del refuerzo de esta. Desgraciadamente, estos informes se publicaron en publicaciones que no estan revisadas para expertos (Freedman et al. 1994, Godder et al. 1994, Martelli 2000, Castellucci 2004). Recientemente se realizó un estudio comparando la resistencia de fractura y las pautas de fracaso de premolares maxilares endodónticamente tratados con un número progresivamente reducido de paredes residuales, estos se restauraron utilizando un material de resinas compuestas con o sin postes translúcidos de fibra de vidrio (Sorrentino et al. 2004). Este estudio mostró que el número de paredes dentales residuales influyó en la resistencia mecánica de los premolares maxilares endodónicamente tratados. En especímenes
con el mismo número de paredes dentales residuales, las cargas más altas de fractura se registraron en dientes restaurados con postes de fibra. Además, en los especímenes restaurados con postes de fibra se observaron fracturas sencillamente restaurables. Si estos datos se pueden validar con estudios clínicos, el concepto de reforzar las estructuras radiculares con el cementado de postes de fibra se establecerá más firmemente.

Un exitoso procedimiento endodóntico es un factor clave de asegurar el éxito en la restauración de dientes con las raíces tratadas. Un tratamiento endodóntico bien realizado se basa en la eliminación de detritos y material orgánico que hay dentro del canal de la raíz (Castellucci 1993) y en la preparación mecánica del canal para recibir un material de obturación (Ingle 1993). La influencia de cementos y de las soluciones irrigadoras se han discutido extensamente en la literatura. Cuando se evaluó el efecto de diferentes regímenes de irrigación en la limpieza de los canales de la raíz que se lograron después del tratamiento endodóntico (Grandini et al. 2002b), se encontró que ninguna de las técnicas utilizadas en ese estudio mostró una eliminación perfecta de la capa de barrillo dentinario y de los detritus. Sin embargo, se notó que una combinación de hipoclorito sódico y un agente quelante puede ayudar a reducir la cantidad de detritus por las paredes del canal. Las funciones de relleno del canal de la raíz deberán sellar esencialmente el canal y prevenir futuras microfiltraciones. En este sentido, la fabricación del poste y su colocación se pueden considerar como partes del tratamiento endodóntico si ellos contribuyen al relleno y al sellado del espacio de canal (Trope 2004). Desgraciadamente, debido a los factores-C altos que hay en los canales radiculares (Morris et al., 2002; Bouillaguet et al., 2003; Goracci et al., 2004), se encontraron dificultades en la cementacion de postes de fibra a la dentina intraradicular con cementos de resina. Se ha sugerido que semejante al uso de cementos no-adhesivos, la fricción de deslizamiento contribuye por una parte substancial a la resistencia a la dislocación de postes cementados en los canales radiculares (Goracci et al., 2005).

La popularidad siempre mas grande que tiene el uso de postes de fibra para la restauración de los dientes endodonticamente tratados ha impuesto la necesidad de una evaluación sistemática de las marcas y tipos diferentes de postes de fibra disponibles comercialmente. Algunos criterios se emplean generalmente, tal como la
composición y la forma del poste, el costo y los procedimientos de cementación, basado en evaluaciones básicas y experimentales. Un estudio ha comparado la resistencia a la fatiga y las características estructurales de tipos diferentes de postes de fibra (Grandini et al. 2004a). Algunas marcas de postes de fibra pueden resistir hasta 2.000.000 de ciclos de fatiga sin afectar su calidad general. En particular la calidad de la adhesión entre los dos componentes de un poste de fibra (las fibras y la matriz de resina de epoxi) puede influir en la calidad del poste mismo. De hecho, las propiedades de fatiga y los impactos estaticos son proporcionales a la fuerza de la interfase relleno/resina en sistemas de composite reforzados con fibra (Zhao et al. 2000, Kessler et al. 2000, Keusch et al. 1999). Un reciente estudio confirmó que aumentando la fuerza de adhesión entre el relleno y la matriz se obtiene como resultado un aumento de las propiedades mecánicas de composites reforzados con fibras (Debnath et al. 2004).

Los procedimientos de cementado son muy importantes en las restauraciones con postes de fibra. El procedimiento recomendado ya se ha descrito en la literatura (Ferrari et al. 2001a y 2001b, Vichi et al. 2002a). El grabado ácido, el uso de un adhesivo de cuarta o quinta generación, y el uso de un cemento de resina de doble-curado proporciona los mejores resultados clínicos. Dejando la solución adhesiva no-polimerizada antes de colocar el cemento (one step procedure), para reducir el tiempo del procedimiento de cementación, se producen resultados desfavorables desde el punto de vista clínico y experimental (Grandini et al. 2004b). Si se coloca una corona, el poste se puede cortar después de la restauración del “core” (muñón). En caso de que se haga una restauración conservadora es preferible ajustar la longitud del poste antes del cementado. El ajuste se debe realizar con un disco de carborundum o una fresa de diamante (Grandini et al. 2002a). De esta manera, es posible cubrir el fin del corte del poste con composite de resina, un material más capaz de resistir que un poste de fibra a el desgasto diente-diente y diente-alimento. Si un poste es lo suficientemente bueno, los procedimientos de corte no afectarán a su integridad estructural.

Un gran desarrollo ocurrió con respecto a los materiales utilizados para la fabricación de postes: el carbono era la primera materia empleada; vidrio, cuarzo y sílice se han utilizado después, aprovechándose de sus propiedades ópticas
traslúcidas. Un desarrollo interesante fue también la modificación del diseño de estos postes, desde el doble-cilindro original, a las formas “endodontica”, y por fin a las formas más recientemente introducidas de la doble-conicidad. De echo la cementación adhesiva ahora confía más en la formación de la zona de interdifusión de resina-dentina y tags de resina que en la retención mecánica del poste dentro del canal (Ferrari et al. 2002). Además, un amplio surtido de tamaños permite la conservación de la dentina residual que se tiene que quitar para lograr una adaptación satisfactoria del poste. El despegamiento es más probable que ocurra en ausencia del deseable ‘ferrule effect’, o a la presencia de una capa excesivamente gruesa de cemento en donde la incitación de burbujas conduce al despegamiento (Ferrari et al. 2000a). La idea de tener un poste anatómico que quede bien en el espacio individual del canal, especialmente con canales de raíz tratados que tienen las formas elípticas, tal como fueron observados en caninos y premolares, sería una situación muy agradable por el clínico. En estos casos, el clínico es forzado a adaptar la estructura dental residual a la forma del poste, mediante la eliminación de una cantidad adicional de dentina o mediante una mayor cantidad y grosor de la capa de cemento. Al contrario, sería deseable que el poste se adaptese a la anatomía del canal de la raíz producida por el tratamiento endodóntico. Esto es verdaderamente la base para la creación de un poste anatómico (Grandini et al 2000, Boudrias et al. 2001a y 2001b). Recientemente el Poste anatómico cementado (RTD, San Egrève, Francia) ha sido introducido (Ferrari et al. 2002). Este nuevo poste es hecho por un poste de DT n.1 que es cubierto por una resina de fotocurado (Lumiglass, RTD, San Egrève, Francia). La resina es capaz, una vez que es introducido en el canal de la raíz, de producir un adecuada forma, reduciendo la cantidad de cemento que debe ser utilizada y estabilizando el poste durante los procedimientos de cementado. La prueba final para un procedimiento clínico es siempre la evaluación clínica. Muchos estudios informaron sobre el uso del poste de fibra para restaurar dientes endodónticamente tratados (Malferrari et al. 2003, Ferrari et al. 2000a y 2000b, Fredriksson et al. 1998, Monticelli et al. 2003, Dallari et al. 1998, Scotti et al. 2002). La mayoría de ellos combinan el uso de restauraciones de poste de fibra con cerámico o coronas de ceramometal. En los últimos años se ha podido observar una enorme expansión en las indicaciones para las restauraciones directas con resina
(Hickel et al. 2004). Así, es interesante evaluar la actuación de postes de fibra cuando ellos fueron utilizados en conjunción con restauraciones directas de resina, sin el cubrimiento adicional de corona. Después de 30 meses de servicio clínico, dientes con raíces tratadas con postes de fibra y restauraciones de composite de resina directa exhibieron unos resultados clínicos favorables y no ocurrieron fracturas de raíces.

Conclusiones y recomendaciones

Las conclusiones y recomendaciones siguientes se pueden deducir de nuestras evaluaciones básicas y clínicas en el uso de postes de fibra en odontología:

1) Los postes de fibra exhiben unas propiedades mecánicas generales buenas y los tipos de fracaso son generalmente más conservadores y favorables que cuando son comparado con postes metálicos.

2) Los procedimientos endodónticos pueden influir en el resultado final de la restauración con el poste. Se debe prestar gran atención en la eliminación de bacterias, detritus y otros materiales que queden dentro del canal de la raíz antes que el relleno sea completado.

3) Los postes de fibra contribuyen al relleno que sella el espacio de canal de la raíz con la ayuda de la cementación adhesiva. Es por esta razón que ellos se pueden considerar como parte del tratamiento endodóntico.

4) Existen varias marcas de postes de fibra. La calidad de la adhesión entre las fibras y la resina puede influir en la calidad final del poste entero, y esto debe ser tenido en cuenta al escoger un poste de fibra junto con la evaluación de la composición, la forma deseada, la evaluación básica y clínica.

5) Por lo que conciernen a los procedimientos de cementado, una adhesión segura entre la unidad cemento-poste de fibra y el canal de la raíz puede ser razonablemente conseguido con el uso del grabado ácido, que ha sido meticulosamente removido del canal de la raíz con una jeringa y un aguja endodóntica.

6) Un adhesivo de cuarta o quinta generación, metido en el canal con la ayuda de un micropincel, y de un cemento de resina de doble-curado puede ser recomendado cuando se utilizan postes de fibra traslúcidas.
7) Un poste individual (Anatomic Post’n Core) puede ser de gran ayuda en una situación clínica donde hay una falta de estructura coronal y canales de raíz en una forma no-redondeado después el tratamiento endodóntico.

8) Los postes de fibra se pueden utilizar con seguridad en combinación con cerámica o coronas de ceramo-metal. Las indicaciones para su uso han sido rápidamente extendidas, y los estudios clínicos recientes indicaron que ellos pueden ser utilizados seguramente como una base para las restauraciones directas de resina. Con el uso de esta técnica, la restauración del diente tratado endodónicamente puede ser más fácil y menos costosa.
Sumário e conclusões

A restauração de dentes tratados endodonticamente permanece ainda como um grande desafio para a grande maioria dos clínicos. Dentro deste campo da Odontologia, os pinos de fibra de vidro ganharam muita importância nos últimos 15 anos. Esta tese contém um estudo sobre diferentes aspectos básicos e clínicos relacionados com a seleção e a utilização destes tipos de pinos.


(Shillimburg HT 1997), uma vez que estes “...não reforçam significativamente os dentes tratados endodonticamente ...” (Sorensen 1984a). O progresso tecnológico no campo de materiais reforçados por fibras melhoraram a estrutura, a forma, e as propriedades ópticas dos pinos reforçados por fibra contemporâneos. Tal progresso levou ao desenvolvimento de materiais que puderam se sobrepor às limitações dos pinos metálicos (platina, ligas ou de titânio), no que diz respeito a sua aparência estética, modo de fratura e performance clínica. Em termos de estética, os pinos de fibra translúcidos foram introduzidos no mercado buscando dar maior suporte às restaurações de dentes anteriores (Vichi et al. 2000a e 2000b, Ferrari et al. 2001a e 2001b, Ferrari et al. 2002, Paul et al. 1998, Heydecke et al. 2002). O conhecimento do comportamento mecânico e o mecanismo de falha dos pinos de fibra é de suma importância, e é demonstrado que os pinos metálicos, quando submetidos a testes de fadiga, tendem a produzir fraturas radiculares irremediáveis. Adicionalmente, as fraturas radiculares que ocorrem quando da utilização de pinos de fibra se localizam em uma porção mais coronária da raiz, além de serem mais facilmente retratadas e reparadas (Akkayan et al. 2002, Cornier et al. 2001, Reagan et al. 1999, Newman et al. 2003). Tal tipo de fratura pode se dar em função da grande quantidade de estrutura dental que deve ser removida quando da inserção de um pino metálico (Stankiewitz et al. 2002). Em casos em que se faz necessário um retratamento endodôntico, pinos de fibra são mais facilmente removidos, quando comparado com pinos metálicos ou cerâmicos (Gesi et al. 2003, Hauman et al. 2003). Como conclusão, pinos de fibra funcionam de maneira efetiva como “ ancoragem” para núcleos de resina composta. Quando comparados com pinos metálicos ou de zircônia, pinos de fibra mostram-se capazes de preservar a estrutura dental remanescente em função de seu comportamento mecânico, bem como em função de seu método de cimentação adesivo.

Ultimamente, técnicas restauradoras com resinas compostas em dentes tratados endodonticamente têm sido descritas, buscando repor a dentina perdida, e possivelmente reforçar a estrutura radicular. Infelizmente, tais artigos foram publicados em publicações que não são acuradamente revisadas (Freedman et al. 1994, Godder et al. 1994, Martelli 2000, Castellucci 2004). Um recente estudo buscou comparar a resistência e o padrão de fratura de pré-molares superiores...
tratados endodonticamente, com diferentes quantidades de paredes remanescentes, que foram restaurados com compósitos; associados ou não a utilização de pinos de fibra de vidro translúcidos (Sorrentino et al. 2004). Este estudo mostrou que o número de paredes dentais remanescentes influenciou significativamente a resistência mecânica de tais dentes tratados endodonticamente. Em dentes com o mesmo número de paredes remanescentes, observou-se uma maior resistência à fratura quando da utilização dos pinos de fibra de vidro. Adicionalmente, fraturas com prognóstico mais favoráveis foram observadas nos dentes restaurados com pinos de fibra. Se tais observações puderem ser validadas em estudos clínicos, o conceito de reforço das estruturas radiculares através da adesão de pinos de fibra estará definitivamente muito melhor embasada.

Um tratamento endodôntico bem realizado é um fator chave para se obter sucesso longitudinal na restauração de dentes tratados endodonticamente. Um tratamento endodôntico bem realizado está baseado na remoção total de debris e materiais orgânicos internamente à porção radicular (Castellucci, 1993) bem como no preparo mecânico propriamente dito, para que seja possível o perfeito acomodamento do material obturador (Ingle 1993). A influência de cimentos e soluções irrigantes têm sido extensivamente discutidas na literatura. Quando da avaliação de diferentes soluções irrigantes na efetividade da limpeza das paredes radiculares após o tratamento endodôntico (Grandini et al. 2002b), pode-se observar que nenhuma das técnicas avaliadas em tal estudo mostrou uma remoção perfeita da camada de “smear layer” e de debris. No entanto, notou-se que a combinação de hipoclorito de sódio e um agente quelante reduz a quantidade de debris ao longo das paredes radiculares. As funções primordiais de um material obturador são essencialmente selar o canal radicular e prevenir uma futura microinfiltração. Neste sentido, a confecção e a colocação de pinos intraradiculares podem ser consideradas parte do tratamento endodôntico, uma vez que contribuem para o preenchimento e o selamento do espaço radicular (Trope 2004). Infelizmente, em função de um alto fator C encontrado nesta região (Morris et al., 2002; Bouillaguet et al., 2003; Goracci et al., 2004), dificuldades substanciais são comumente encontradas quando da cimentação de pinos de fibra à dentina intraradicular com o auxílio de cimentos resinosos. Postula-se que similarmente aos cimentos não-adesivos, uma parte
substancial da resistência ao deslocamento de pinos de fibra aderidos às paredes radiculares está ligada a forças friccionais (Goracci et al., 2005).

A popularização do uso de pinos de fibra para a restauração de dentes tratados endodonticamente impuseram uma necessidade de avaliação sistemática dos mais diferentes tipos de pinos disponíveis no mercado. Alguns critérios são usualmente empregados, tais como a composição e o formato do pino, o custo e os procedimentos de cimentação, sempre baseados em avaliações básicas e experimentais. Um estudo comparando a resistência a fadiga e as características estruturais dos mais diferentes tipos de pinos de fibra foi desenvolvido (Grandini et al. 2004a). Algumas variedades de pinos de fibra podem resistir a mais de 2.000.000 ciclos de fadiga in vitro, sem que haja efeitos em sua integridade. Particularmente, a qualidade adesiva entre os dois componentes inerentes a um pino de fibra (as fibras e a matriz de resina epóxica) pode influenciar a qualidade do pino propriamente dita. Como via de regra, as propriedades de impacto estático e de fadiga são proporcionais a resistência da interface carga/resina nos sistemas de compósito reforçado por fibras (Zhao et al. 2000, Kessler et al. 2000, Keusch et al. 1999). Um recente estudo confirmou que aumentando a força de união entre as partículas de carga e a matriz, obtêm-se melhorias significativas nas propriedades mecânicas dos compósitos reforçados por fibras (Debnath et al. 2004).

Em se tratando de pinos de fibra, os procedimentos de cimentação apresentam extrema importância. Os procedimentos recomendados encontram-se amplamente descritos na literatura (Ferrari et al. 2001a e 2001b, Vichi et al. 2002a). As etapas de condicionamento ácido, a utilização de um sistema adesivo de quarta ou quinta geração, aliado a um cimento resinoso de polimerização dual, possibilitam os melhores resultados clínicos. A tentativa de deixar o sistema adesivo sem ser polimerizado antes da colocação do cimento (procedimento em passo único), buscando reduzir o tempo clínico de cimentação, produz resultados desfavoráveis, tanto do ponto de vista experimental quanto do ponto de vista clínico (Grandini et al. 2004b). Se uma coroa será posteriormente efetuada, o pino pode ser ajustado após a confecção de um núcleo de preenchimento. Em casos de restaurações diretas, deve-se ajustar o comprimento do pino anteriormente ao procedimento de cimentação. Tal ajuste pode ser feito com um disco de carborundum ou com uma ponta diamantada.
(Grandini et al. 2002a). Desta maneira, é possível recobrir a porção mais coronal do pino com resina composta, um material que apresenta maior resistência ao desgaste que os pinos de fibra de vidro. Partindo do princípio que se está trabalhando em um pino de boa qualidade, os procedimentos de corte não virão a afetar a sua integridade estrutural.

Muitos avanços nos materiais utilizados para a fabricação de pinos foram obtidos nos últimos tempos: o carbono foi o primeiro material utilizado; vidro, quartzo e sílica foram em seguida aplicados, buscando tirar vantagem de suas propriedades ópticas translúcidas. Alterações interestantes foram também empreendidas no “design” de tais pinos, o originalmente duplo cilíndro, com formato endodôntico, para os mais recentes de “double-tapered”, ja que a cimentação adesiva está principalmente baseada na formação da zona de interdifusão resina-dentina e na formação de “tags” de resina, em detrimento de uma maior adaptação e de retenção mecânica do pino dentro do canal radicular (Ferrari et al. 2002). Além disso, a variedade de tamanhos permite uma maior conservação da dentina radicular que provavelmente teria que ser removida para buscar uma melhor adaptação do pino. A quebra da adesão (debonding) está mais propensa a acontecer na ausência de um efeito férula, ou na presença de uma camada de cimento muito espessa, onde uma maior quantidade bolhas incorporadas levam a falha adesiva (Ferrari et al. 2000a). A ideia de se ter um pino individualizado que se encaixa justamente no canal radicular é extremamente interessante, especialmente quando lida-se com canais radiculares que apresentam formato elíptico, comumente observados em caninos e pré-molares inferiores. Nestes casos, o clínico é forçado a adaptar a estrutura radicular residual ao formato do pino, através da remoção de uma determinada quantidade de dentina. Contrariamente, o ideal seria que o pino se adaptasse à anatomia do canal radicular produzida após o tratamento endodôntico. Sem dúvida, tal problemática levou ao desenvolvimento de pinos anatômicos (Boudrias et al. 2001a e 2001b). Recentemente, o sistema Anatomic Post’n Core (RTD, St Egrève, France) foi introduzido no mercado (Ferrari et al. 2002). Este novo pino é feito por um DT n. 1 que em seguida é coberto por uma resina fotopolimerizável (Lumiglass, RTD, St Egrève, France). Tal resina de reembasamento, uma vez introduzida no canal radicular, permite uma boa adaptação às paredes radiculares, além de reduzir a
quantidade de cimento a ser utilizada e estabilizando melhor o pino durante os procedimentos de cimentação.


Conclusões e recomendações

As seguintes conclusões e recomendações podem ser extraídas a partir de nossas avaliações clínicas e laboratoriais, quanto a utilização de pinos de fibra em Odontologia:

1) Pinos de fibra apresentam ótimas propriedades mecânicas, com padrões de fratura mais conservadores e favoráveis, quando comparados com pinos metálicos.

2) Os procedimentos endodônticos podem influenciar o resultado final da restauração com pinos. Extremo cuidado deve ser tomado quanto à remoção de bactérias, debris e outros materiais dentro do canal radicular previamente ao fechamento completo da estrutura.

3) Pinos de fibra contribuem para o selamento do espaço radicular adjuntamente com a cimentação adesiva. Por tal razão, tal etapa operatória pode ser considerada como parte do tratamento endodôntico.

4) Existem diversos tipos de pinos de fibra. A qualidade da adesão entre as fibras e a resina influenciam a qualidade final de todo o pino, e tal fato deve ser levado em
conta quando da seleção de um pino de fibra, juntamente com a composição e o formato, além das avaliações básicas e experimentais.

5) No que concerne aos procedimentos de cimentação, a obtenção de uma adesão confiável entre o pino de fibra de vidro e o cimento resinoso pode ser conseguida através da técnica do condicionamento ácido, que deve ser enxaguado com água do canal radicular meticulosamente, com auxílio de uma agulha endodôntica.

6) Um sistema adesivo de quarta ou quinta geração, aplicado ao canal com auxílio de um “microbrush”, e um cimento resinoso de polimerização dual são recomendados quando da utilização de um pino de fibra translúcido.

7) Um pino individualizado (Anatomic Post’n Core) pode ser de grande valia em situações clínicas de grande perda de estrutura coronária, bem como após tratamentos endodônticos onde não é possível obter os canais com formato cilíndrico.

8) Pinos de fibra podem ser seguramente utilizados em conjunto com coroas metalocerâmicas ou em cerâmica pura. Suas indicações estão se expandindo rapidamente, e estudos clínicos recentes indicam que podem ser utilizados como alicerce para restaurações diretas em resina composta. Através do uso desta técnica, a restauração de dentes tratados endodonticamente pode ser facilitada, e muito menos custosa.
Complete list of references


Ferrari M, Vichi A, Grandini S. Influence of adhesive application technique on efficacy of bonding to root canal walls: An SEM investigation. Dent Mat 2001b;17, 422-9


Griffith AA. The phenomena of rupture and flow in solids. Philosophical Transactions of the Royal Society of London (Series A) 1920; A221: 168-98.


175


Mason PN. Transactions of International ADM meeting, Siena 2001.


176


Scotti R. Ricostruzioni preprotesiche con perni in fibra di quarzo: esperienza clinica a 18 mesi. Odontoiatria adesiva e ricostruttiva, S. Margherita Ligure, 2000; 21-27.


Sorrentino R, Tanganelli E, Ferrari M. Effect of Post and Core Restorations and the Number of Residual Dental Walls on the Resistance to Fracture of Endodontically Treated Maxillary Premolars. Submitted to Am J Dent 2004.


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List of papers part of this thesis

Grandini S, Balleri P, Ferrari M.

Grandini S, Balleri P, Ferrari M.
Scanning electron microscopic investigation of the surface of post after cutting. 

Grandini S, Sapio S, Simonetti M.
Use of Anatomic post’n core for reconstructing an endodontically treated tooth: a case report. 

Grandini S, Sapio S, Goracci C, Monticelli F, Ferrari M.
SEM evaluation of the cement layer thickness after the luting procedures of two different posts.
*Journal of Adhesive Dentistry* 2004, in press.

Grandini S, Sapio S, Goracci C, Monticelli F, Ferrari M.
A one step procedure for luting glass fibre posts: an SEM evaluation

Grandini S, Goracci C, Monticelli F, Tay F, Ferrari M.
Fatigue resistance and structural characteristics of fiber posts: three-point bending test and SEM evaluation.
*Dental Materials* 2004, in press.

Grandini S, Goracci C, Monticelli F, Tay F, Grandini R, Ferrari M.
Clinical evaluation of the use of fiber posts and direct resin crowns for restoring endodontically-treated teeth.

Grandini S.
The Anatomic post’n core
List of abstracts part of this thesis

Grandini S, Narducci P, Porciani PF, Ferrari M.
SEM investigation of the surface of fiber posts after cutting procedures.
ADM transactions, 232, vol 15, 2001

Grandini S, Ferrari M, Goracci G, Bertelli E.
Quantitative evaluation of dentin morphology in root canals after shaping and
irrigation of the endodontic space.
Journal of Dental Research 81 (special issue B) 2002, #52, pag B238

Grandini S, Ferrari M, Balleri P, Vichi A.
Clinical trial of fiber posts luted with self-curing Excite in combination with an
experimental resin cement.
Journal of Dental Research 81 (special issue A) 2002, #198, pag A52

Grandini S, Balleri P, Goracci C, Monticelli F, Bertelli E, Ferrari M.
Scanning Electron Microscopic Evaluation of two different techniques for luting
glass fiber post
Abstract from Conseuro meeting, Munich, Germany, June 5-8, 2003

Grandini S, Borracchini A, Goracci C, Monticelli F, Ferrari M.
SEM Study to Compare the Luting Procedures of Two Different Fiber Posts
Journal of Dental Research 82 (Special Issue B) 2003, #1442, B-192

Grandini S, Goracci C, Monticelli F, Tay FR, Ferrari M.
Fatigue Resistance of Different Kinds of Fiber Posts
Journal of Dental Research 82 (Special Issue B) 2003, #2935, B-376

Grandini S, Vichi A, Borracchini A, Ferrari M.
Direct resin restorations with a fiber post: a case report
Accepted for IADR meeting, Istambul 2004
Complete list of papers

Ferrari M, Grandini S.
Use of enamel dentinal adhesives systems: clinical implications. (Les adhésifs amélo-dentinaires: implications pratiques)
*Realités Cliniques* 2000; 11:419-429

Ferrari M, Vichi A, Grandini S.
Efficacy of different adhesive techniques on bonding to root canal walls: An SEM evaluation.

Vichi A, Grandini S, Ferrari M.
Clinical procedure for luting glass-fiber posts.

Ferrari M, Vichi A, Grandini S, Goracci C.
Efficacy of a self-curing adhesive resin cement system on luting glass-fiber posts into root canals: an SEM investigation.

Grandini S, Balleri P, Ferrari M.

Vichi A, Grandini S, Ferrari M.
Comparison between two clinical procedures for bonding fiber posts into a root canal: a microscopic investigation.

Grandini S, Sapio S, Ferrari M.
Treatment of crown fractures. (Traitement des fractures coronaires)

Grandini S, Balleri P, Ferrari M.
Scanning electron microscopic investigation of the surface of post after cutting.

Ferrari M, Grandini S, Simonetti M, Monticelli F, Goracci C.
Influence of a microbrush on bonding fiber posts into root canals under clinical conditions.
Vichi A, Grandini S, Davidson CL, Ferrari M.
An SEM evaluation of several adhesive systems used for bonding fiber posts under clinical conditions.

Ferrari M, Vichi A, Grandini S, Geppi S.
Influence of microbrush on efficacy of bonding into root canals

Grandini S, Sapio S, Simonetti M.
Use of Anatomic post’n core for reconstructing an endodontically treated tooth: a case report.
*Journal of Adhesive Dentistry* 2003, vol 5, num. 3, pag. 243-247

Monticelli F, Grandini S, Goracci C, Ferrari M.
Clinical behavior of translucent fiber posts and luting and restorative materials: a 2-year report.
*International Journal of Prosthodontics* 2003, volume 16, number 6, pag. 593-596

Porciani PF, Grandini S.
A Six-Week Study to Evaluate the Anticalculus Efficacy of a Chewing Gum Containing Pyrophosphate and Tripolyphosphate”
*Journal of Clinical Dentistry* 14:11-13, 2003

Porciani PF, Grandini S.
Anticalculus Efficacy of a Chewing Gum with Polyphosphates in a Twelve-Week Single-Blind Trial
*Journal of Clinical Dentistry* 14: 2003

Grandini S, Sapio S, Goracci C, Monticelli F, Ferrari M.
SEM evaluation of the cement layer thickness after the luting procedures of two different posts.
Accepted in the *Journal of Adhesive Dentistry* 2003.

Goracci C, Ferrari M, Grandini S, Monticelli F, Tay FR.
Bonding of a self-adhesive resin cement to dental hard tissues
Accepted in the *Journal of Adhesive Dentistry* 2003

Monticelli F, Goracci C, Grandini S, Garcia-Godoy F, Ferrari M.
Scanning electron microscopic evaluation of fiber post-resin core units built up with different resin composite materials
Accepted for publication in the *American Journal of Dentistry* 2003

Grandini S, Sapio S, Goracci C, Monticelli F, Ferrari M.
A one step procedure for luting glass fibre posts: an SEM evaluation
Grandini S, Goracci C, Monticelli F, Tay F, Ferrari M.
Fatigue resistance and structural characteristics of fiber posts: three-point bending test and SEM evaluation.
Accepted for publication in Dental Materials 2004

In vivo and in vitro permeability of 1-step self-etch adhesives
Complete list of abstracts

Grandini S, Magheri P, De Marco M.
The utilization of a new dental dam for endodontics.

Bertini F, Grandini S, Magheri P.
Multidisciplinary approach in a case of complicated fracture of a central incisor.
Pag 76

Porciani PF, Magheri P, Grandini S.
Multidisciplinary approach to endodontic retreatments.

Porciani PF, Magheri P, Grandini S.
Multi-disciplinary management of endodontic retreatments.
Abstracts from IFEA fourth endodontic world congress. Jerusalem 1998, pag.1

Fabianelli A, Vichi A, Grandini S, Ferrari M, Davidson CL.
Influence of self-etching priming bonding systems on sealing ability of class II restorations: leakage and SEM evaluation.
Atti del congresso delle Società Europee di Conservativa (Conseuro 2000), pag 26

Ferrari M, Grandini S, Vichi A, Mannocci F, Lopes B, Fuzzi M.
One-bottle and three steps adhesive systems used for bonding fiber posts into root canals under clinical conditions: a SEM investigation.
Atti del congresso delle Società Europee di Conservativa (Conseuro 2000), pag 27

Porciani PF, Grandini S.
Clinical evaluation of a new endo-system: The A.E.T.

Porciani PF, Grandini S.
The 10th Biennial Congress of the European Society of Endodontology, 4-6 October 2001, Munich

Fuzzi M, Grandini S.
Clinical application of ceramic bonded restorations.
ADM transactions, 51, vol 15, 2001

Lima Mourao R, Reis Hannas A, Grandini S, Ferrari M.
Microleakage evaluation of the marginal adaptation of different restorative-adhesive combinations in class II composite restorations.
ADM transactions. 167, vol. 15. 2001
Fabianelli A, Ferrari M, Dagostin A, Grandini S.
Operator variability influence on marginal seal of class II resin restorations.
ADM transactions, 213, vol 15, 2001

Grandini S, Narducci P, Porciani PF, Ferrari M.
SEM investigation of the surface of fiber posts after cutting procedures.
ADM transactions, 232, vol 15, 2001

Grandini S, Ferrari M, Goracci G, Bertelli E.
Quantitative evaluation of dentin morphology in root canals after shaping and irrigation of the endodontic space.
Journal of Dental Research 81 (special issue B) 2002, #52, pag B238

Ferrari M, Grandini S, Fabianelli A, Vichi A.
SEM study on the efficacy of a self-activating adhesive system used for bonding fiber posts into root canal. Journal of Dental Research 81 (special issue B) 2002, #420, pag B282

Fabianelli A, Grandini S, Bertelli E, Ferrari M.
Clinical trial of Gradia indirect restorations.
Journal of Dental Research 81 (special issue A) 2002, #2654, pag A333

Ferrari M, Cagidiaco MC, Grandini S, Bertelli E, Dolci G.
Effect of concentration on tooth whitening in a highly stained population.
Journal of Dental Research 81 (special issue A) 2002, #3486, pag A429

Borracchini A, Fabianelli A, Grandini S, Ferrari M.
Clinical trial of Empress II, self-curing Excite and Multilink luting materials.
Journal of Dental Research 81 (special issue A) 2002, #2634, pag A331

Porciani PF, Grandini S.
Anticalculus efficacy of a chewing-gum containing Pyrophosphate: a six week study.
Journal of Dental Research 81 (special issue A) 2002, #2155, pag A276

Grandini S, Ferrari M, Balleri P, Vichi A.
Clinical trial of fiber posts luted with self-curing Excite in combination with an experimental resin cement.
Journal of Dental Research 81 (special issue A) 2002, #198, pag A52

Grandini S, Balleri P, Goracci C, Monticelli F, Bertelli E, Ferrari M.
Scanning Electron Microscopic Evaluation of two different techniques for luting glass fiber post
Proceedings of Conseo meeting, Munich (Germany), 5-8 June 2003
Monticelli F, Goracci C, Balleri P, Grandini S, Ferrari M.
Clinical behavior of translucent fiber posts and luting restorative materials: a 2-year report.
Proceedings of Conseuro meeting, Munich (Germany), 5-8 June 2003

Porciani PF, Grandini S, Sapio S.
Plaque accumulation in One day with Four Chewing-gums in the absence of Oral Hygiene
Journal of Dental Research 82 (Special Issue B) 2003, #1056, B-144

Monticelli F, Grandini S, Goracci C, Ferrari M, Tay FR.
Transmission Electron Microscopic Evaluation of a Self-adhesive Material Luted to Different Dental Substrates.
Journal of Dental Research 82 (Special Issue B) 2003, #1439, B-192

Grandini S, Borracchini A, Goracci C, Monticelli F, Ferrari M.
SEM Study to Compare the Luting Procedures of Two Different Fiber Posts
Journal of Dental Research 82 (Special Issue B) 2003, #1442, B-192

Fabianelli A, Grandini S, Goracci C, Ferrari M.
One-year Clinical Trial of Gradia Direct Class II Restorations
Journal of Dental Research 82 (Special Issue B) 2003, #1472, B-196

Monticelli F, Goracci C, Grandini S, Bertelli E, Balleri P, Ferrari M.
Scanning Electron Microscopic Evaluation of Fiber Post-Resin Core Unit
Journal of Dental Research 82 (Special Issue B) 2003, #1953, B-254 Journal of dental Research 82 (Special Issue B) 2003, #1056, B-144

Grandini S, Goracci C, Monticelli F, Tay FR, Ferrari M.
Fatigue Resistance of Different Kinds of Fiber Posts
Journal of Dental Research 82 (Special Issue B) 2003, #2935, B-376

Ferrari M, Grandini S, Colon P.
Composite inlays (Les inlays composites)
Atti del Congresso ADF, Parigi, 2003. pagine 169-171

Chersoni S, Acquaviva GL, Ferrari M, Grandini S, Passley DH, Prati C, Tay FR.
In vivo fluid movement through adhesive in post space
IADR meeting, Honolulu 2004, Paper #46694

Borracchini A, Vichi A, Grandini S, Goracci C, Ferrari M.
Spectrophotometric observations about the chromatic correspondence of some shade guides
Accepted for IADR meeting, istanbul 2004
Goracci C, Sadek F, Grandini S, Vichi A, Borracchini A, Tay FR, Ferrari M.
Push-out bond strength and TEM evaluation of luted fiber posts
Accepted for IADR meeting, Istambul 2004

Grandini S, Vichi A, Borracchini A, Ferrari M.
Direct resin restorations with a fiber post: a case report
Accepted for IADR meeting, Istambul 2004

Vichi A, Grandini S, Borracchini A, Ferrari M
Color correspondence between Vita Shade guide and three different composite
Accepted for IADR meeting, Istambul 2004