

Effect of post design on endodontically restored teeth

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Resum

En aquest article es fa una revisió de l'efecte del disseny del pern en les prestacions de les dents endodonciades a partir de l'anàlisi de la bibliografia i dels treballs dels autors. De l'estudi es conclou que existeixen proves suficients de l'efecte d'alguns paràmetres en determinades característiques de la dent restaurada: la longitud del pern facilita la retenció de la restauració, que és major en el cas dels perns actius, seguits dels cilíndrics, mentre que els cònics presenten menor retenció. El diàmetre del pern ha de mantenir-se inferior a la meitat de l'amplària de l'arrel. Amb els perns de fibra s'obtenen distribucions de tensions menys sensibles al diàmetre o a la longitud del pern que amb els metàl·lics. No existeixen conclusions clares sobre altres aspectes de la restauració, com ara l'efecte de la forma del pern en la seva resistència, l'efecte del diàmetre en la retenció o el comportament dels diferents sistemes davant de càrregues de fatiga. Els treballs previs dels autors han permès desenvolupar un model biomecànic per a elements finits, validat amb dades experimentals, que pot servir d'ajuda per a clarificar l'efecte de cada paràmetre en les prestacions finals de la restauració.

Paraules clau: Pern endodòntic, disseny de perns, restauració dental, biomecànica dental

Abstract

In this article a review is carried out on the effect that post design has on the performance of endodontically treated teeth by analysing the bibliography and the works by the authors themselves. We can conclude from this study that sufficient evidence exists of the effect that some parameters have on specific characteristics of the restored tooth. Post length facilitates retention, which is greater for active posts, followed by cylindrical posts, and tapered posts. The diameter of the post must be less than half the root width. Stress distributions that are less susceptible to post diameter or post length are better obtained with fibre posts than with metallic ones. However, no clear conclusions exist for other aspects of restoration, such as how the shape of the post affects its resistance, how the diameter affects retention or how different systems perform under cyclic loading. The previous works by the authors have made it possible to obtain a finite element biomechanical model, validated with experimental data, which could help to clarify the effect of each parameter on the final properties of tooth restoration.

Keywords: Endodontic post, post design, dental restoration, dental biomechanics

Endodontic treatment is one of the most common techniques in present-day odontology due to the tendency to save teeth whenever possible. The devitalised tooth, resulting from endodontics, is less resistant than the original tooth as a consequence of the loss of tooth structure [1]. The use of intraradicular posts has become a widespread technique for restoring teeth that have lost considerable coronal tooth structure as a means to support the final restoration and to join it to the root [2, 3]. After removing the tooth pulp, the intraradicular post is introduced into the devitalised root. A core is placed over the root and the post and an artificial crown creates an external appearance, similar to that of the original tooth (Fig. 1), although in general with inferior mechanical properties.

Indeed, and contrary to what was thought in the past, it has been demonstrated that posts do not reinforce the endodontically treated tooth, but rather they weaken it by predisposing it to a fracture [4-6]. Several studies have shown that the failure rate of these restorations after several years of service is high either because of root fractures or loss of retention. According to some authors [7, 8], the prevalence of failures due to vertical root fractures ranges between 2% and 5%, and in most cases these complications cannot be treated [9]. The appearance of such vertical fractures has been related to the tooth restoration process and post design [10-12].

Several types of posts are found in the literature [2, 13]. Originally, cast post-core systems were used as a single metal alloy unit (Fig. 2). Subsequently, prefabricated posts made out of stainless steel, titanium or precious metals were used, while prefabricated fibre posts were more recently introduced. Cast post-core systems take longer to make and involve an intermediate laboratory stage in which the retention system is created,

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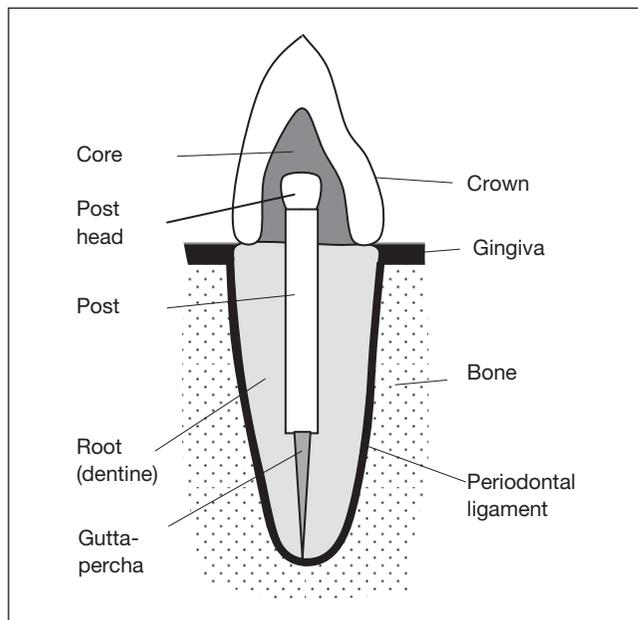


Figure 1. Endodontic restoration with post, core and crown.

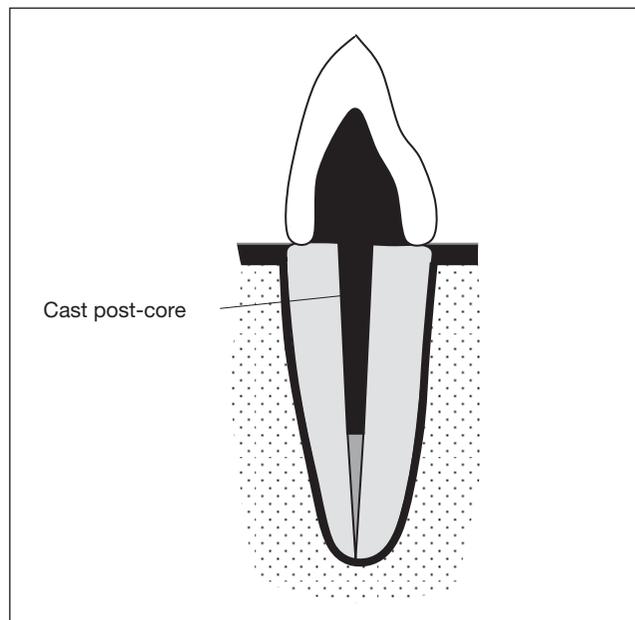


Figure 2. Cast post-core system.

which make the whole process more costly. In comparison, prefabricated posts do not need this intermediate stage, which means that the whole restoration process can be performed in a single visit, which is obviously easier and cheaper [2]. Nonetheless, the adaptation of the prefabricated posts to the root canal may be less accurate [14].

Different post designs have been proposed to obtain the best properties, from the perspectives of easy assembly, the aesthetics of the final restoration, the mechanical strength and the retention ability. Post design is defined by different parameters such as the material used, post length or post diameter, the longitudinal shape of the post (cylindrical, conical, cylindrical-conical, threaded or others, see Fig. 3), or the surface treatments to facilitate adhesion. The effect of these design parameters on the final performance has been studied in part in numerous research works [10, 15-22]. Nonetheless, there are no clear conclusions about the effect of these parameters and the interrelation between them, as the wide variety of currently existing designs on the market reveals.

As regards the methodology used in the previous works, three main lines are distinguished: in vitro experimentation, retrospective clinical studies and studies with finite element models. The first usually covers the effect of the specific parameters (material, post design, post length or post diameter) on resistance or the retention of the restoration work [4, 5, 10, 15, 23-26]. The majority of these works are static experiments and very few studies have been made of cyclic loading or fatigue [27-31]. Retrospective studies are less common given that they require longer times to be performed, often years, and they are based on the study of failures in restorations performed on real patients [8, 32-35]. Although the working conditions are the current oral dynamic conditions in these studies, the results may be conditioned by loss of control of other parameters that are outside the scope of what is being studied, as a result of the patient's own variability. Finally, the number of studies based on finite element models has considerably in-

creased in recent years [36-42]. Finite element models permit a highly controlled analysis of one or several specific parameters on a single tooth model, thus allowing for better comprehension of either the individual effect or that combined with different parameters. In contrast, the clinical application of their results is conditioned by the accuracy of the model and its previous validation based on experimental data.

The objective of this article is to obtain conclusions about the effect that the different post design parameters have on the success of endodontic restoration and to propose future lines of research into those parameters for which no clear conclusions have been drawn in previous works. This study is based on the bibliography and on the authors's own research.

Effect of post diameter

Several studies have analysed the influence of post diameter on the resistance of endodontic restoration. It is evident that post stiffness increases as post diameter augments [43], although this intrinsically entails a greater risk of restoration failure as it weakens the tooth as a consequence of eliminating a greater amount of dentine [44-47]. Some works conclude with recommendations for the diameter, i.e., it should not exceed half the root width [45] or a third of this width [48], or that the diameter on the apical side should not exceed 1 mm [49]. Pilo et al. [50] recommend a preserving form of restoration in such a way that a minimum thickness of 1 mm of dentine around the post at any point is preserved. In line with these recommendations, conical posts are a good alternative as they are of a variable diameter which reduces in an apical direction, that is, in the same direction as the root diameter. Some studies, however, have provided poorer resistance results and more catastrophic forms of failure in conical posts than in their cylindrical counterparts [51].

The effect that post diameter has on the stress distribution

on the tooth is not the same for all post materials. Several works [40, 42] have indicated that the use of metallic posts has a greater effect than fibre posts because the elastic modulus of fibre posts is more comparable with that of dentine. Furthermore, the authors recently published a paper [42] which studied how the diameter of intraradicular posts affects the biomechanical performance (fracture strength and stress distribution) of restored teeth using two different post materials (glass fibre and stainless steel). First, an experimental fracture strength test was performed, and second, the finite element technique was used to develop a model of the restored tooth. From the experimental data, a significant influence was observed for the teeth restored with stainless steel posts while no statistically significant differences were observed for teeth restored with glass fibre posts. The model confirmed these results, by predicting smaller stresses in dentine for the glass fibre post which is explained by the more similar elastic modulus of this material to that of dentine. The lesser effect of diameter using the glass fibre post has also been observed in other works [40].

According to the literature, the effect that an increased post diameter has on retention is not as important as the effect of post length [19, 47]. Although some studies have verified a significant increase in retention with the diameter [25, 47], others did not note this effect [52].

Effect of post length

The ideal post length has been widely reported [2, 3, 53, 54]. One widespread recommendation is that post length should be about three quarters of root length, and that 3 to 5 mm of apical gutta-percha must be preserved to maintain the apical seal. These recommendations, however, are not always supported by experimental studies. Very few experimental studies have been performed to compare the biomechanical performance of restored teeth as a function of post length [35, 36, 39, 47, 52, 55, 56]. All these cited studies, except the last, used metallic posts and focused mainly on the effect on retention and not on the resistance of the tooth. Retention studies allow us to state that the use of a longer post, rather than a thicker post, positively influences the retentive strength [47]. Only three of the above-mentioned works [36, 39, 56] studied the influence of post length on stress distribution. The first two works [36, 56] studied metallic post systems by means of two-dimensional finite element models, and drew differing conclusions. The first predicted minor changes in the stress patterns for the length variations considered; the only effect of post length was a change in the location of the stress concentrations that occurred at the post apex. Conversely, the second predicted higher stress as the length of the metallic post decreased.

To solve this contradiction, a recent study published by the authors [42] studied how varying the length of intraradicular posts affected the biomechanical performance (fracture strength and stress distribution) of restored teeth using two different post materials (glass fibre and stainless steel). First, an experimental fracture strength test was performed, and sec-

ond, the finite element technique was used to develop a model of the restored tooth. From the experimental data, no statistically significant influence was observed for the teeth restored with either stainless steel posts or glass fibre posts. According to this finding, no clear dependency of the maximum stress on post length was predicted by the model.

Other experimental results from the literature [35, 36] also corroborate the finding that the fracture load in metallic post systems is not clearly dependent on post length. It is interesting to observe the low dependency on post length in relation to the biomechanical performance in both the post systems under consideration. As reported by Davy [36], the real effect of variations in length was to change the location of the stress concentrations that occurred at the post apex in all cases. This finding, together with the experimental observation that better retention is achieved by increasing post length [13], enables us to recommend the use of the longest possible post for restoration. However, it may not always be possible to use a long post, especially when the remaining root is short or curved. Several studies suggest that it is important to preserve 3 to 5 mm of apical gutta-percha to maintain the apical seal [57, 58].

Effect of post design

Cast posts are the same shape as the root (Fig. 2), whereas prefabricated posts may be a variety of shapes. Stockton [46] mentioned more than 100 different models of prefabricated posts. Two large groups emerge depending on how prefabricated posts are secured to the root: passive and active. Active posts are threaded into the dentine while passive posts are cemented to the dentine using a suitable adhesive. Passive posts have become more commonplace in recent years [3].

Active posts provide greater retention than passive posts, as confirmed by several studies undertaken in recent decades [15-18, 59]. In contrast, threaded posts require more meticu-

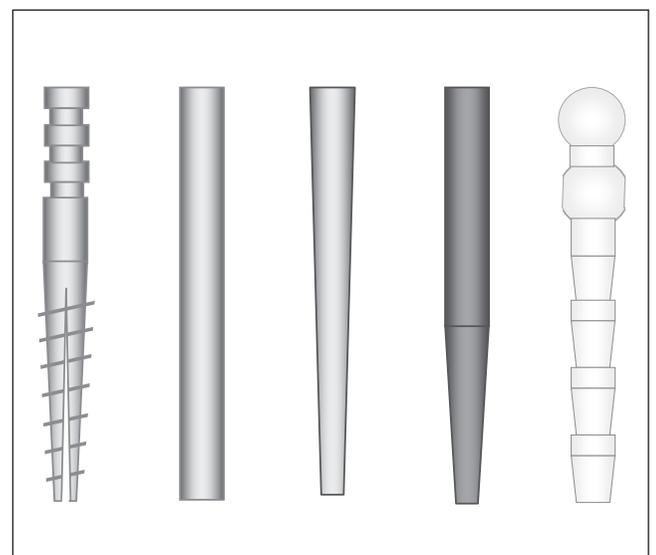


Figure 3. Post design. From left to right: split shank threaded, cylindrical, conical, cylindrical with a conical tip, cylindrical-conical sectioning.

lous preparation and assembly, and produce stress concentration on the dentine [10, 60]. Some active post designs, such as Flexi-Post (see Fig. 3), have a split, flexible shank to reduce stress on the apical area and to facilitate dentine removal during assembly, although retention is reduced to achieve such advantages [20]. The effect of the thread shape or its spacing remains unclear. While some works report a better retention with threads with less pitch [20], others obtain a better result with threads that are sharper and have a greater pitch [23].

The group of passive posts (see Fig. 3) includes cylindrical (like ParaPost), tapered (like EndoPost) or cylindrical with a tapered end (i.e., Filpost). There are also posts with two or more cylindrical-conical sections (like ParaPost Fiber White). Even though tapered posts, or those with a tapered end, preserve a larger amount of dentine, since they adapt better to the root shape, cylindrical posts have been demonstrated to be more retentive [19, 20, 24, 61, 62]. On the other hand, tapered posts produce high hydrostatic pressures close to the apical side of the post [10]. A method that improves the retention of passive posts is surface treatment to increase roughness or to provide a more retentive shape. Nergiz et al. [21] verified that retention increased significantly in tapered titanium posts by sandblasting or the use of circumferential grooves. On the other hand, glass fibre posts with surface abrasion also increase retention with respect to smooth surface posts [22].

The effect that post design has on resistance and on the durability of the restoration is difficult to clearly establish given the fact that any comparative study made with two post systems or more involves changes that not only affect the design itself, but also the diameter, length or material. A study of the clinical analysis available suggests that the properties that active posts offer are inferior to cast posts [63]. Milot et al. [4] indicate that the effect of post design on the resistance of the restoration is of lesser importance if most of the dentine structure is maintained. After a 10-year retrospective study, Weine et al. detected very few failures using conical posts [32] while Torbjörner et al. [8] in a 5-year retrospective study reported significantly greater success with parallel-sided serrated posts than with cast posts.

Very few studies in the literature have focused on the influence of post design on retention under torsional loads which are occasionally seen in the mouth, especially in the anterior teeth [15, 16, 64]. Some authors recommend the use of anti-rotation systems [2, 15, 16] such as keys and pins in the root of the tooth. Such systems may avoid cementing in threaded posts, and enable the post to be unscrewed should it be necessary [15].

One final aspect related to post design is the shape of the head, which in the case of prefabricated posts must contribute to ensuring the union between the post and the core which supports the crown [13]. There are different post models on the market with varying head shapes that aim to improve retention and prevent the core from rotating in relation to the post. There are very few studies in the literature that examine how the shape of the head affects the retention of restoration [65-67], and no conclusive results are available for this particular factor.

Effect of post material

Considerable controversy exists regarding the optimal choice of material for a post and core. Several *in vitro* studies have determined the resistance to fracture of post-restored teeth under static loading and found lower [68, 69], equal [70, 71] or higher strengths [39, 72, 73] of teeth restored with fibre posts than those restored with metallic posts. Studies have shown [39, 73] fractures that enable the repair for glass and quartz fibre post systems and non-restorable fractures for zirconium, titanium and stainless steel post systems.

In a recent paper the authors [39] studied how varying the material of intraradicular posts affects the biomechanical performance (fracture strength and stress distribution) of restored teeth. Two different post materials were used, glass fibre and stainless steel. First, an experimental fracture strength test was performed, and second, the finite element technique was used to develop a model of the restored tooth. From the experimental data, the material had a significant influence on the fracture load, with higher fracture loads for the glass fibre posts. The finite element model matched these results with higher stress when using stainless steel posts. The results of the simulations performed made it possible to identify the difference in the elastic moduli between the post and the dentine and core as the origin of stress concentrations at the post-core-cement interface that weakened the restored tooth, despite introducing a stronger post. Other works are consistent with this finding [37, 40]. Nowadays it is commonly accepted that better performance is achieved if the stiffness (or modulus of elasticity) of the material for the post is similar to that of dentine [13]. Some manufacturers of carbon and glass fibre posts purport that these posts have a transverse elastic modulus that is as small as that of dentine and are, therefore, less damaging to the tooth.

Very few clinical studies have compared fibre posts with metal posts. One such study [74] showed that teeth restored with 9 mm bonded fibre posts had a significantly higher survival rate after 4 years than teeth restored with tapered metallic posts.

The use of all-ceramic restorations has increased considerably due to rising aesthetic demands. The application of an all-ceramic crown after the insertion of a metallic post-and-core compromises the aesthetic appearance of the all-ceramic crown. In this respect, glass fibre post systems have improved the aesthetics of teeth restored with posts and cores, especially in the anterior region [2].

Effect of other parameters

There are other aspects related to the clinical procedure, which interrelate with post design influencing the success of restorations with posts and cores. Of these aspects, two clearly stand out: the effect of the adhesive used to cement the post and the so-called ferrule effect.

Although a wide range of adhesives is commercially available, one of the most widespread is zinc phosphate cement

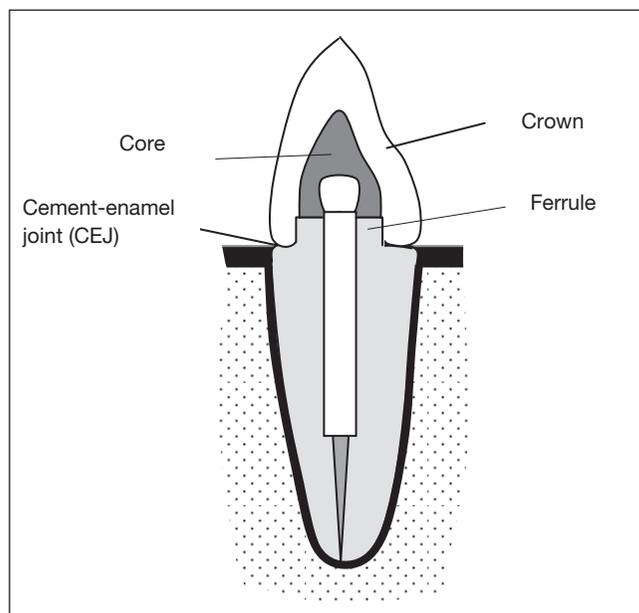


Figure 4. Post restoration with ferrule preparation.

[13]. Some studies suggest that the new composite resin adhesives help reinforce the tooth structure and improve retention [75], particularly with fibre posts or when post length is short [24]. Nonetheless, results are inconsistent in the literature [46].

On the other hand, numerous past works maintain that preparing a ferrule or circumferential collar may improve the resistance of a post-core system [76-80]. The ferrule effect (Fig. 4) is achieved using a metallic piece or by preparing a circumferential portion of dentine around the post on top of the cement-enamel joint. With the ferrule, the crown is supported a few millimetres in the apical direction in relation to the level of the joint between the core and the dentine. For the cast post-and-core systems it is sometimes the core itself that moves in an apical direction to form the circumferential collar. According to the cited literature, the best results are achieved with a ferrule of between 1 and 2 mm. Stankiewicz et al. made a review of works on this subject [81], and recommended a ferrule preparation of at least 1.5 mm provided this does not eliminate part of the remaining tooth structure.

Discussion and conclusions

By reviewing previous works in this field some conclusions can be derived that sufficiently confirm the effect that some parameters have on post design for endodontically treated teeth. One such conclusion is that threaded posts most favour retention, followed by cylindrical posts, with tapered posts providing less retention. On the other hand, posts must be as long as possible to improve retention, although a certain length of gutta-percha is recommended for the apical seal. Post diameter must be limited to avoid any weakening of the root dentine. As regards the material, fibre posts provide restorations of a resistance that is less susceptible to the choice of the length or diameter of the post and facilitate subsequent retreatments in case of failure.

Nonetheless, numerous existing studies do not provide such clear conclusions about the effect that some parameters have on the properties of the post-core system. Therefore neither the effect of post diameter on retention nor the effect of the shape-design of the post and its head on resistance apparently provide clear definitive conclusions. Furthermore, there are no clear conclusions as to whether fibre posts or traditional posts made out of metallic materials are more recommendable despite some of the aforementioned advantages of fibre posts under static conditions. Finally, we wish to point out that most of the existing studies are based on static tests, which offer few conclusions about the performance of the various post systems under fatigue conditions, such as those which take place in real oral conditions.

The fact that the vast majority of existing works are experimental has made it a difficult task to draw clear conclusions about the effect that different post design parameters have on the final system given the variability of some of the uncontrollable parameters, such as the geometry of the specimens, the dentist's clinical practice or the experimental set-up. In many cases, comparing two post systems inevitably involves varying many parameters (shape, material, diameter, length) which makes it difficult to differentiate the exact effect of each one on the biomechanical properties of the system. The use of appropriately validated finite element models may be of great help in facilitating the study of the independent effect of each parameter. The authors' previous works have looked into this issue by developing a validated model for the study of endodontic restorations. This model has proven to be suitable for studying the influence of post dimensions and material on the biomechanical static performance of restored teeth since the model's predictions matched up very well with the experimental results obtained from the fracture strength test. It could be a useful tool for studying the influence of other post design variables on the biomechanical performance of restored teeth, by means of simulations. These analyses will generate data that may help to reduce post-treatment iatrogenic lesions.

Acknowledgements

The authors acknowledge the Spanish government and the EU for financing this research through the "DPI2006-13432" project.

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