Direct or indirect post crowns to restore compromised teeth: a review of the literature

T. A. Owen*[1] and M. W. Barber[2]

Key points

- Suggests there is no strong evidence to suggest either direct or indirect posts are more successful in most clinical situations.
- Suggests that certain canal shapes may benefit from a cast post in order to achieve close fit of the post to the dentine structure.
- Highlights that the condition of the remaining tooth structure is one of the most important factors in predicting the success of a post crown restored tooth.

Post crowns are restorations which utilise the root canal space to improve the retention and resistance form of teeth which lack coronal tooth structure. In recent years there have been significant developments in the materials, systems and evidence-base surrounding the provision of post crowns. This review aims to refresh the general dental practitioner's (GDPs) knowledge of the different factors that must be considered when placing a post crown, and how these factors can help guide the dentist in their decision to provide either a direct or indirect post and core.

Introduction

A post is indicated for teeth with minimal tooth structure in order to improve the resistance and retention form of the final tooth preparation. These can be placed directly using prefabricated posts, or indirectly using posts made by a laboratory. This review will focus on the extent to which post design may influence success of post crowns and consider the significance of the condition of the tooth to be restored.

When is a post needed?

In posterior teeth we can often gain retention from the pulp chamber and the coronal third of the root canals using a Nayyar core restoration. However, when a tooth is single rooted this option is lost. Posts do not strengthen teeth, but will help to increase retention and resistance of a restoration when coronal tooth structure is limited. The height of the remaining tooth structure is important, but taper is also significant when determining its ability to successfully retain an indirect restoration. Where there is significant taper, adhesive cements may provide additional retention.

A ferrule is the portion of the crown which encompasses the core of a prepared tooth to strengthen the dowel post. However, traditionally in dentistry the ferrule has been referred to as the coronal tooth structure of which the ferrule of the crown wraps around. Where possible a ferrule should be achieved. To retain a single unit crown, 3 mm of preparation height is generally accepted as an ideal minimum.[1] Clinically, this is not always possible, and it is in these situations that dentists tend to rely on posts and cores. This recommendation mainly takes into account the desirable retention and resistance form of preparations for crowned teeth, and there is little evidence base to suggest that in specific clinical situations a post crown will increase a tooth's survival. It may therefore be wise to suggest a post crown is indicated where: a preparation height of 3 mm cannot be achieved; there is a poor taper and/or poor width to the remaining tooth structure.

Factors to consider during the provision of post crowns

Post material

There are a wide range of materials on the market, each having specific properties that make the material favourable for use as a post (Fig. 1). Metal posts have the longest history of use and are extremely popular for cast posts because metals can be utilised for lost wax casting. More recently, techniques to mill posts from various materials using CADCAM programmes have become available. Aside from metal posts, prefabricated carbon fibre, glass fibre reinforced composite posts and ceramic materials are now also popular choices for post crowns.

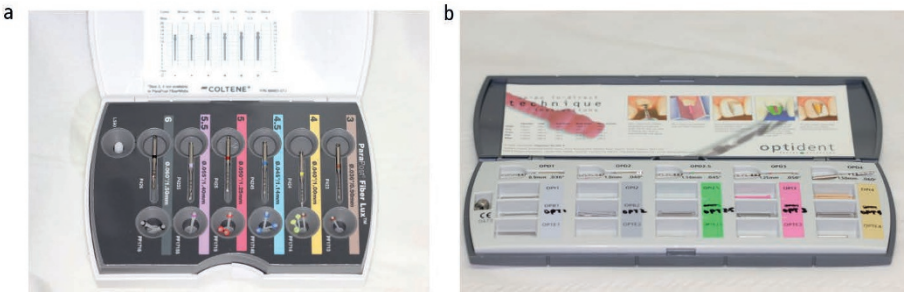

Fig. 1 a) and b) examples of post and core systems

[1]Aintree University Hospital, Maxillofacial unit, Lower Lane, Liverpool L9 7AL; [2]Academic Unit of Restorative Dentistry, School of Clinical Dentistry, Claremont Crescent, Sheffield, S10 2TA
*Correspondence to: Thomas Owen
Email: thomasowen150@hotmail.co.uk

Refereed Paper. Accepted 4 December 2017
DOI: 10.1038/sj.bdj.2018.218

Metal posts

A retrospective study of up to ten years comparing cobalt chromium cast, titanium prefabricated, and stainless steel prefabricated posts found no significant difference in survival between metal types and a mean survival estimate of 83%.[2] The relative strengths and weaknesses of metal posts when compared to other post materials are discussed in more detail in the following sections.

Glass fibre reinforced composite resin posts

Fibre posts although not as rigid as metal, have a number of key advantages. Firstly, the use of a fibre reinforced composite post allows bonding of the post to resin cement compared with traditional mechanical retention with non-adhesive cements. This is particularly advantageous where there is minimal ferrule or perhaps a shorter post is required. Fibre posts are also aesthetic, as they are typically closer to a natural shade, and therefore have less of an effect on the appearance of translucent crowns. Lastly, these fibre posts are more flexible than metal or ceramic posts, producing a more homogenous stress distribution on the canal.[3] However, a systematic review found no conclusive evidence that this decreases the chance of root fracture.[4] The ability of glass fibre posts to survive over long time periods has been demonstrated. A retrospective study of 109 custom fibre posts found a mean overall survival estimate of approximately seven and a half years.[5]

There are two main ways to make a fibre post. The first is the use of a prefabricated fibre post and the second is a custom made fibre post at the chairside. A randomised controlled trial of six years found that prefabricated fibre posts tend to survive longer than custom fibre posts.[6] One explanation for this is that operator error from making a fibre post chairside may introduce weaknesses or design flaws into a post.

Ceramic

Ceramic posts are another aesthetic post choice as they are available in light shades. Zirconia is a popular ceramic and may be milled to create a custom indirect post or used prefabricated. Two *in vitro* studies comparing zirconia and metal posts under loads found that zirconia posts would tend to fracture due to brittleness, rather than distort and bend like the metal post.[7,8] This may be advantageous because ceramic posts may fracture before the tooth does which is a serious but potentially less detrimental outcome for a tooth. However, retrieval of a fractured zirconia post can prove to be extremely challenging.

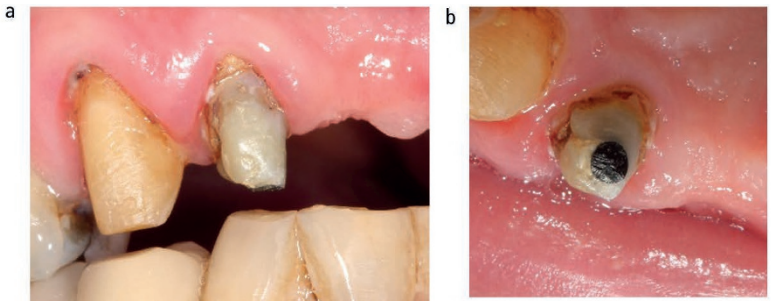

Fig. 2 a) Photograph showing a failed composite core and b) carbon fibre post in situ. Note the black colour of the post showing through the composite. This tooth was part of a failed six-unit bridge which was dismantled

Carbon

Similar to fibre posts, using finite element analysis, carbon posts showed a more homogenous stress distribution along the root canal surface when compared to metals.[9] However, the disadvantage of carbon posts is that they are dark, non-tooth coloured materials which are hard to mask, so will often shine through translucent restorations or the root (Fig. 2).

Post design

As with the wide choice of materials, there are many designs of posts and often the design is linked to the properties of the material.

Active versus passive

Passive posts sit in the prepared canal space without engaging with the dentine directly for retention, whereas active posts are those which engage the root dentine via threads and gain retention from this, typically acting like screws (Fig. 3). An active post engages with the dentine and therefore exerts a force upon it which may cause microcracks that propagate. A systematic review found that active screw posts decrease tooth survival over that of passive posts due to the resultant stresses from placement of an active post.[10] Since then, a randomised controlled trial found that 93.5% of passive glass fibre posts and only 75.6% of metal screw posts survived one year.[11] Furthermore, the vast majority of the active post failures were root fracture. For this reason, active (threaded) posts are no longer recommended.

Dimensions of post

A longer post is more retentive than a shorter post because of the increased surface area contact between the post, cement and tooth.[12] However, teeth naturally taper and as they do so, the risk of perforating laterally increases. An *in vitro* study exerting forces on post crowned teeth found that longer posts also increase the chance of root fracture as they are thought to concentrate stress on the thinner apical portion under load.[13] Despite the findings in this study, other studies have found shorter fibre posts increase the chance of tooth fracture due to production of higher lateral forces.[14] It is important for the post preparation to extend well beyond the level of the alveolar bone, as this provides 'bracing' against these lateral forces. Furthermore, dowel preparation disturbs the apical seal of gutta-percha. This must be weighed against the negatives of shorter posts and so it is generally accepted that the apical 3-6 mm of gutta-percha should remain undisturbed to preserve the apical seal.[15–17]

Width of post is another compromise between the properties of the material and preservation of tooth structure. Too thin and the material risks fracture under load; too thick and excess tooth structure will be removed resulting in weakened root structure. *In vitro* studies have shown that wider posts increase the risk of tooth fracture.[18] If a wider post is required, a material with a higher Young's modulus of elasticity such as glass fibre is favoured as the stiffness of a thick metal post could induce significant stress on the canal wall.[19]

Post taper

Another disputed area of post crowns is whether to place a tapered or a parallel post. A taper will reduce apical preparation of the dowel space but retention of the post will also decrease.[20] Tapered posts may also act as a wedge to concentrate lateral forces on the root. Cast posts are often naturally tapered as the coronal portion of the root canal and the pulp chamber may be significantly tapered.

Official journal of the British Dental Association.

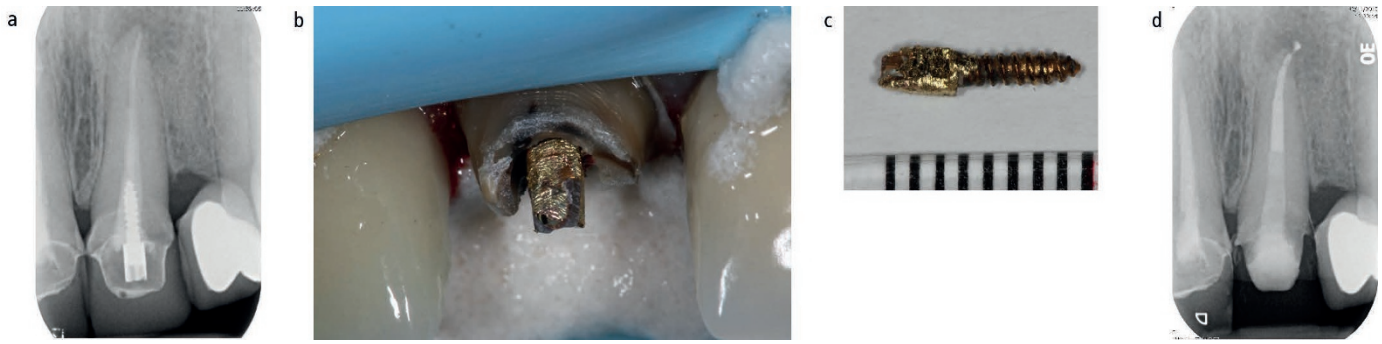

Fig. 3 Radiographs and photographs of a threaded post being removed and replaced. a) Pre-treatment radiograph showing rlatively short threaded post in situ. b) The post following removal of the surrounding core material and after a number of revolutions to unscrew the post in a coronal direction. c) The threaded post following removal with a millimetre scale below. d) Post-treatment radiograph showing endodontic retreatment and a new composite fibre post in situ with a provisional crown

Despite *in vitro* studies showing differences in retention of parallel and tapered posts, a retrospective study found that 98.6% of parallel fibre posts compared to 96.7% of tapered fibre posts survived a mean observation period of 5.3 years, which was not statistically significant.[21]

Surface design

Posts with a roughened surface, as opposed to a smooth surface, can provide micromechanical retention to increase retention of the post when cemented.[22] This can commonly be produced through air abrasion techniques. Macromechanical features such as grooves also increase retention and aid venting of cement for accurate seating of posts.[22] Surface design is not thought to influence stress distribution.[3]

Cementation

In the past, zinc phosphate-based cements have been a popular choice for cementation of post crowns as these cements have been found to provide good retention.[23] These cements rely on mechanical retention by filling the gap between the post and the root canal space. However, although some authorities still advocate their use for the cementation of metal posts, zinc phosphate cements have now largely been succeeded by cements which can adhere to the tooth, post or both. These include glass ionomer cements (GIC), resin-modified glass ionomer cements (RMGIC), and composite resin cements.

Composite resin, glass ionomer and resin-modified glass ionomer cements

Adhesive bonding allows an improved marginal seal between the post and the tooth and improves the mechanical retention of the post core unit when compared to zinc phosphate.[24,25] This can be beneficial, especially when using thinner or shorter posts. For composite resin bonding to have its maximum benefit, the resin must be allowed to enter the dentinal tubules of the root canal. After mechanical preparation of root canals a smear layer is left which impedes entry of resin cements into the tubules. A study using chlorhexidine, ethylenediaminetetraacetic acid (EDTA) and then phosphoric acid to prepare the root canal surface showed an increase in bond strength of fibre posts.[26] However, studies have also shown that chemicals such as EDTA used before resin cementation of fibre posts could decrease the retention by interfering with the resin bond[27] and may in fact increase microleakage when using glass ionomer cements.[28] The use of resin cements with dentine bonding agents and silane has been found to be advantageous. A systematic review of *in vitro* studies concluded that the use of self-adhesive resin cements may improve retention of glass fibre posts.[29] A further systematic review and meta-analysis of *in vitro* fibre post silanisation found that silanisation can improve the retention of glass fibre posts but only when a fibre post surface is pre-treated and then silanated.[30] Pre-treatment included a wide range of non-specific approaches such as air abrasion, etching with phosphoric acid, tribochemical coating and the use of chemicals such as hydrogen peroxide. Excluding the use of self-adhesive resin cement, another systematic review of *in vitro* studies found a 43.4% increase in retention of glass fibre posts pre-treated before silanisation.[31] It may therefore be worthwhile pre-treating/cleaning a fibre post prior to silanisation, however, the results are from low quality studies of which the majority have a high risk of bias. Metals and certain ceramics are hard to bond, but certain proprietary cements for example, Panavia 21 (Kuraray, Japan) are formulated to provide chemical adhesion to metal.

Though removal of cemented posts is often challenging, a study looking at retrievability of posts found that zinc phosphate cemented posts can be retrieved reliably with ultrasonics with a low (0.06%) root fracture rate.[32] Even with magnification and ultrasonic techniques the removal of resin-cemented posts has been found to take significantly longer than both GIC and zinc phosphate cemented posts.[33]

The main issue with RMGIC as a post cement is hygroscopic expansion, which, when compared with other cements may cause higher stresses to develop in the intraradicular dentine and decrease fracture strength of the post-crowned tooth. Studies have shown the degree to which it expands varies on the specific RMGIC chosen and how it is placed, but the impact of its effect on cementing post and cores is not well demonstrated.[34]

The evidence comparing direct and indirect (cast) post crowns

The traditional method of fabricating post crowns indirectly has been by casting metals rather than more recent advancements in milling materials using CADCAM. Cast post crowns are those which are referred to as indirect in the following evidence.

A randomised controlled trial comparing cast metal posts to prefabricated fibre posts found a 97.1% and 91.9% survival over three years respectively, although this was not statistically significant.[35] As mentioned earlier, a retrospective study of up to ten years compared cobalt-chromium cast, titanium prefabricated and

stainless steel prefabricated posts and found no significant difference of survival probability and a mean survival estimate of 83%.[2] A different 15-year study found a significant 78.7% survival of resin posts, compared to 55.4% survival of cast metal posts.[36] The aforementioned retrospective studies have significant limitations as many of the factors potentially influencing success of post crowns; materials, dimensions of post and ferrule to name a few will not have been consistent. Many *in vitro* studies have shown that cast non-precious metal posts tended to have the highest fracture resistance when compared to carbon, resin fibre and prefabricated metal posts.[37–40] However, the evidence for this is conflicted as *in vitro* studies also can be found supporting an increased fracture resistance of glass fibre posts when compared to prefabricated and cast metal posts.[41,42]

Condition of the tooth to be restored

Although this review focusses mainly on specifics of post material and design, one of the most significant prognostic factors when placing a post in a tooth, is consideration of the condition of the tooth itself. It is important to assess the length and width of a tooth/root, amount of remaining tooth structure supragingivally, degree of periodontal support and occlusal design.

A literature review on the 'ferrule effect' from 2002 concluded that a significant increase in survival is seen when the ferrule extends at least 1.5 mm coronally.[43] In retrospective clinical studies, it was found that survival of different post crown materials was related to the number of walls and amount of coronal structure left to support a post crown.[21,44] An up to 17-year controlled study of post crowns found those placed in teeth with substantial coronal dentine survived longer than those with minimal dentine, the type of post and core did not affect survival.[45] It is better to achieve some degree of ferrule, even if incomplete. It has been found that a 3 mm partial buccal ferrule on premolars, canine and incisor teeth produced significantly higher fracture loads when compared to controls with no ferrule.[46] For molar teeth with posts, a similar conclusion has been found. When restoring the distal root of lower molars and palatal of upper molar roots with cast and fibre post systems *in vitro* a ferrule of 2 mm was significant in fracture resistance of the molars and this was regardless of post type.[47]

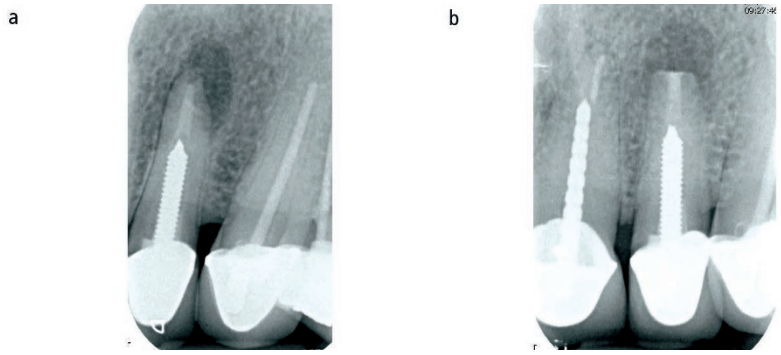

Fig. 4 a) A long direct metal post in 22 with associated periapical radiolucency. b) In this case a decision was made not to attempt removal of the post and instead periapical surgery was undertaken including root-end resection and retrograde filling with MTA

Where teeth have limited supragingival structure, gingivectomies, crown lengthening or orthodontic extrusion may be required to produce an increase in ferrule height. Each of these increases complexity, potentially cost for the patient and treatment time, but where possible it gives the chance to obtain a ferrule.

This can, however, have an adverse effect on the integrity of the final restoration. Firstly, the crown-root ratio will be reduced. Secondly, the further apically we take a ferrule on the root, the thinner the width of ferrule, which will weaken it.

One *in vitro* study examined the effect of crown lengthening decoronated mandibular second molars to produce a 2 mm ferrule vs those without ferrule using cast posts.[48] It was found that those which had a ferrule via crown lengthening failed at a lower static load than those with no ferrule.[48] Obviously the types of forces in the mouth are not solely static loads and under different testing techniques the outcomes may be different.

Subgingival margins are possible in some cases, but biological width, cleansability, and aesthetics are important to consider.

Tooth function

The occlusal forces and function of a post-crowned tooth is also associated with failure. A review concluded that non-axial forces have been linked to failure of restorations, tooth and cement and that having a favourable occlusion is more important than the type of post used.[49] There is some limited evidence to suggest posts placed in molars and premolars may survive longer than incisors and canines.[50] Ideally, a molar or premolar post crown would not be in group function to minimise these non-axial forces. Fatigue fracture lines are not caused by compression which makes axial forces favourable. For some teeth such as canines and incisors, non-axial forces may be hard to avoid due to their function, but it would be recommended to make excursive contacts lighter on these teeth. The use of post-crowned teeth as abutments for bridges or removable partial dentures may also decrease survival.[50] Lack of proximal contacts on a post crown has also been found to have three-times higher failure than those with at least one proximal contact.[50] Contact with adjacent teeth limits direction of movement for a post crown and will help to support a tooth. If adjacent teeth are missing there are fewer teeth to share the load.

Clinical reasoning for direct and indirect post crowns

The vast majority of evidence for post crowns comes from *in vitro* studies and these largely focus on mechanical fatigue testing and resulting fracture rates. Failure of post crowns can also occur due to post de-bond, poor coronal seal leading to periapical infection and caries, to name just a few (Fig. 4). These studies use different methodologies which make it difficult to compare results reliably. It is therefore clear that more randomised controlled trials are needed to evaluate the numerous variables that affect post crown choice. However, randomised controlled trials are time-consuming and expensive to undertake, and therefore relatively few are undertaken in this field. The following conclusions are based on the available evidence.

Direct posts

Directly placed posts allow an immediate permanent coronal seal and obviate the introduction of errors during the post-fabrication stage; however, certain canal shapes may still

Official journal of the British Dental Association.

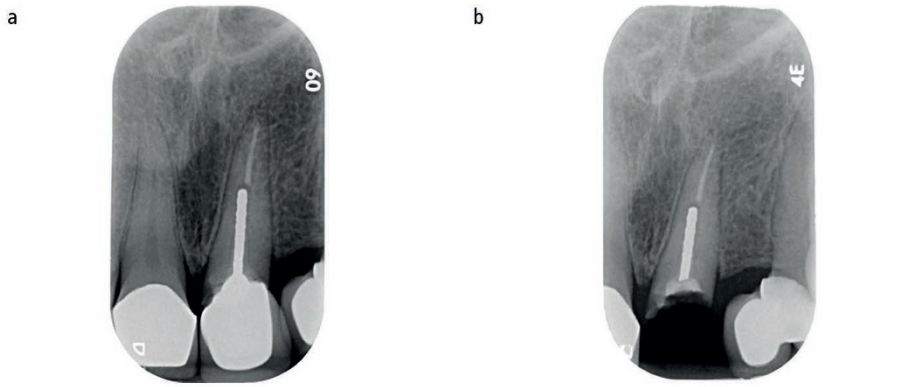

Fig. 5 a) Radiograph showing a cast metal post, diverging slightly mesially from the canal. The post is narrow, especially coronally which may indicate a casting error. b) The same post only a few weeks after initial placement showing a fracture at the narrow coronal aspect and loss of the crown. The tooth was deemed unrestorable at this point and scheduled for extraction

benefit from a cast post in order to achieve close fit of the post to the dentine structure. Posts typically come with a kit of burs that allow the correct size dowel preparation for the corresponding post. This allows well-fitting prefabricated posts to be cemented immediately after preparation. This will reduce the risk of coronal leakage as no provisional post crown restoration is needed. Prefabricated posts made from glass fibre also show good fracture resistance, flexibility, the ability to bond to adhesive cements and aesthetic advantages of a light-coloured post core. However, the problem with prefabricated posts is that posts may not accurately fit oval or excessively tapered canals which may lead to a thick cement layer. The decision of whether to place a tapered or a parallel post should be based on an individual tooth basis. In an ideal situation the placement of a parallel post will help increase the retention of a post and, if not too wide, should not excessively weaken the surrounding root dentine.

Indirect posts

Indirect cast posts inherently allow greater ability of the post shape to conform to the natural taper of teeth or any irregularities in the post preparation and allow a good fit of the post; this is particularly useful in tapered and oval-shaped canals. However, production of a cast post requires an impression of the dowel from which lost wax casting can be used to produce a post. This allows the post to adapt well to the post space but also may lead to an error in the impression or lost wax cast which could lead to a poorly fitting or weak post (Fig. 5). Cast metal posts have also been shown in many *in vitro* tests to fracture teeth in an unfavourable manor upon failure and do not work optimally with adhesive cements unless specific brands are used. Despite the apparent flaws in cast and prefabricated posts, the aforementioned randomised controlled trial showed no significant difference in survival rates of cast metal posts and prefabricated fibre posts.[35,37]

Conclusion

The overwhelming factor in success of post crowns is likely the condition of the tooth to be restored and how it will function in the mouth. A ferrule should be achieved where possible, but should not come at the expense of destroying unnecessary tooth tissue, leading to a thin fragile dentinal wall. Axial forces are desirable as these may increase the life of the restoration and produce less stress on the walls of the root canal. The available evidence is equivocal regarding the optimum post system and material. However, there appears to be an increasing move towards prefabricated glass fibre reinforced composite posts cemented using an adhesive cement. Silanisation and pre-treatment of a fibre post may also act to further increase the retention of these posts. Glass fibre posts have the ability to flex with the forces placed on a tooth and adhesively bond to resin cement which aids retention and coronal seal. There is also some limited evidence to suggest a reduction in root fracture when using fibre posts compared to metal posts and these also offer improved aesthetics for teeth that will receive a translucent restoration.

1. Huang YC, Lin CL, Ko EW Effects of proximal grooves and abutment height on the resistance of resin-cemented crowns in teeth with inadequate resistance: An *in vitro* study. *Biomed J* 2015; **38:** 336–341.
2. Gómez-Polo M, Llidó B, Rivero A, Del Río J, Celemín A. A 10-year retrospective study of the survival rate of teeth restored with metal prefabricated posts *versus* cast metal posts and cores. *J Dent* 2010; **38:** 916–920.
3. Silva N R, Castro C G, Santos-Filho P C *et al.* Influence of different post design and composition on stress distribution in maxillary central incisor: Finite element analysis. *Indian J Dent Res* 2009; **20:** 153–158.
4. Figueiredo F E, Martins-Filho P R, Faria-E-Silva A L. Do metal post-retained restorations result in more root fractures than fiber post-retained restorations? A systematic review and meta-analysis. *J Endod* 2015; **41:** 309–316.
5. Piovesan E M, Demarco F F, Cenci M S, Pereira-Cenci T. Survival rates of endodontically treated teeth restored with fiber-reinforced custom posts and cores: a 97-month study. *Int J Prosthodont* 2007; **20:** 633–639.
6. Ferrari M, Cagidiaco M C, Goracci C *et al.* Long-term retrospective study of the clinical performance of fiber posts. *Am J Dent* 2007; **20:** 287–291.
7. Pontius O, Nathanson D, Giordano R, Schilder H, Hutter J W. Survival rate and fracture strength of incisors restored with different post and core systems and endodontically treated incisors without coronoradicular reinforcement. *J Endod* 2002; **28:** 710–715.
8. Heydecke G, Butz F, Strub J R. Fracture strength and survival rate of endodontically treated maxillary incisors with approximal cavities after restoration with different post and core systems: an in-vitro study. *J Dent* 2001; **29:** 427–433.
9. Coelho C S, Biffi J C, Silva G R, Abrahão A, Campos R E, Soares C J. Finite element analysis of weakened roots restored with composite resin and posts. *Dent Mater J* 2009; **28:** 671–678.
10. Peroz I, Blankenstein F, Lange K P, Naumann M. Restoring endodontically treated teeth with posts and cores-a review. *Quintessence Int* 2005; **36:** 737–746.
11. Schmitter M, Rammelsberg P, Gabbert O, Ohlmann B. Influence of clinical baseline findings on the survival of 2 post systems: a randomized clinical trial. *Int J Prosthodont* 2007; **20:** 173–178.
12. Farina A P, Cecchin D, Spazzin A O, Pires-de-Souza Fde C, Dartora N R, Mesquita M F. Evaluation of resistance to displacement of metal posts with different lengths. *Indian J Dent Res* 2012; **23:** 613–616.
13. Chuang S F, Yaman P, Herrero A, Dennison J B, Chang C H. Influence of post material and length on endodontically treated incisors: an *in vitro* and finite element study. *J Prosthet Dent* 2010; **104:** 379–388.
14. Jindal S, Jindal R, Gupta K, Mahajan S, Garg S. Comparative Evaluation of the Reinforcing Effect of Different Post Systems in the Restoration of Endodontically Treated Human Anterior Teeth at Two Different Lengths of Post Space Preparation – An *in vitro* study. *J Dent (Tehran)* 2013; **10:** 124–133.
15. Cheung W. A review of the management of endodontically treated teeth. Post, core and the final restoration. *J Am Dent Assoc* 2005; **136:** 611–619.
16. Pappen A F, Bravo M, Gonzalez-Lopez S, Gonzalez-Rodriguez M P. An *in vitro* study of coronal leakage after intraradicular preparation of cast-dowel space. *J Prosthet Dent* 2005; **94:** 214–218.
17. Rahimi S, Shahi S, Nezafati S, Reyhani M F, Shakouie S, Jalili L. *In vitro* comparison of three different lengths of remaining gutta-percha for establishment of apical seal after post-space preparation.*J Oral Sci* 2008; **50:** 435–439.
18. Tey K C, Lui J L. The effect of glass fiber-reinforced epoxy resin dowel diameter on the fracture resistance of endodontically treated teeth. *J Prosthodont* 2014; **23:** 572–581.
19. Kaur A, N M, N S, Kumari A, Shetty A. A comparative study of intra canal stress pattern in endodontically treated teeth with average sized canal diameter and reinforced wide canals with three different post systems using finite element analysis. *J Conserv Dent* 2010; **13:** 28–33.
20. Sahafi A, Peutzfeldt A, Asmussen E, Gotfredsen K. Retention and failure morphology of prefabricated posts. *Int J Prosthodont* 2004; **17:** 307–312.
21. Signore A, Benedicenti S, Kaitsas V, Barone M, Angiero F, Ravera G. Long-term survival of endodontically treated, maxillary anterior teeth restored with either tapered or parallel-sided glass-fiber posts and full-ceramic crown coverage. *J Dent* 2009; **37:** 115–121.
22. Nergiz I, Schmage P, Platzer U, Ozcan M. Bond strengths of five tapered root posts regarding the post surface. *J Oral Rehabil* 2002; **29:** 330–335.

Official journal of the British Dental Association.

23. Hanson E C, Caputo A A. Cementing mediums and retentive characteristics of dowels. *J Prosthet Dent* 1974; **32:** 551–557.
24. Gaikwad A, Singh K P, Ranganath L M, Jain J K, Patil P, Babar G. Fracture resistance of teeth restored with various post designs and cemented with different cements: An *in-vitro* study. *J Int Oral Health* 2015; **7:** 33–37.
25. Bolhuis HP, de Gee A J, Pallav P, Feilzer A J. Influence of fatigue loading on the performance of adhesive and nonadhesive luting cements for cast post-and-core buildups in maxillary premolars. *Int J Prosthodont* 2004; **17:** 571–576.
26. Liu C, Liu H, Zhu S. Effect of different irrigating solutions on bonding strength of fiber post to root canal. *Hua Xi Kou Qiang Yi Xue Za Zhi* 2011; **29:** 210–213.
27. Faria-e-Silva A L, Menezes Mde S, Silva F P, Reis G R, Moraes R R. Intra-radicular dentin treatments and retention of fiber posts with self-adhesive resin cements. *Braz Oral Res* 2013; **27:** 14–19.
28. Zheng Z, Liu C, Lan J, Gao X. Factorial analysis of root canal irrigants and cements on coronal microleakage after cementing metal post-cores. *Hua Xi Kou Qiang Yi Xue Za Zhi* 2014; **32:** 242–245.
29. Sarkis-Onofre R, Skupien J A, Cenci M S, Moraes R R, Pereira-Cenci T. The role of resin cement on bond strength of glass-fiber posts luted into root canals: a systematic review and meta-analysis of *in vitro* studies. *Oper Dent* 2014; **39:** 31–44.
30. Moraes A P, Sarkis-Onofre R, Moraes R R, Cenci M S, Soares C J, Pereira-Cenci T. Can silanization increase the retention of glass-fiber posts? A systematic review and meta-analysis of *in vitro* studies. *Oper Dent* 2015; **40:** 567–580.
31. Skupien J A, Sarkis-Onofre R, Cenci MS, de Moraes R R, Pereira-Cenci T. A systematic review of factors associated with the retention of glass fiber posts. *Braz Oral Res* 2015; **29:** 1–8.
32. Abbott P V. Incidence of root fractures and methods used for post removal. *Int Endod J* 2002; **35:** 63–67.
33. Soares J A, Brito-Júnior M, Fonseca D R *et al.* Influence of luting agents on time required for cast post removal by ultrasound: an *in vitro* study. *J Appl Oral Sci* 2009; **17:** 145–149.
34. Emamieh S, Ghasemi A, Torabzadeh H. Hygroscopic expansion of aesthetic restorative materials: one-year report. *J Dent (Tehran)* 2011; **8:** 25–32.
35. Sarkis-Onofre R, Jacinto Rde C, Boscato N, Cenci M S, Pereira-Cenci T. Cast metal vs. glass fibre posts: a randomized controlled trial with up to 3 years of follow up. *J Dent* 2014b; **42:** 582–587.
36. Hikasa T, Matsuka Y, Mine A *et al.* A 15-year clinical comparative study of the cumulative survival rate of cast metal core and resin core restorations luted with adhesive resin cement. *Int J Prosthodont* 2010; **23:** 397–405.
37. Pereira JR, do Valle A L, Shiratori F K, Ghizoni J S, Bonfante E A. The effect of post material on the characteristic strength of fatigued endodontically treated teeth. *J Prosthet Dent* 2014; **112:** 1225–1230.
38. Solomon C S, Osman Y I. *In vitro* comparison of endodontic posts in structurally compromised roots of maxillary incisors. *SADJ* 2011; **66:** 220–223.
39. Marchi G M, Mitsui F H, Cavalcanti A N. Effect of remaining dentine structure and thermal-mechanical aging on the fracture resistance of bovine roots with different post and core systems. *Int Endod J* 2008; **41:** 969–976.
40. Maccari P C, Cosme D C, Oshima H M, Burnett LH Jr, Shinkai R S. Fracture strength of endodontically treated teeth with flared root canals and restored with different post systems *J Esthet Restor Dent* 2007; **19:** 30–36.
41. Sonkesriya S, Olekar S T, Saravanan V, Somasunderam P, Chauhan R S, Chaurasia V R. An *in vitro* comparative evaluation of fracture resistance of custom made, metal, glass fiber reinforced and carbon reinforced posts in endodontically treated teeth. *J Int Oral Health* 2015; **7:** 53–55.
42. Aggarwal R, Gupta S, Tandan A, Gupta N K, Dwivedi R, Aggarwal R. Comparative evaluation of fracture resistance of various post systems using different luting agents under tangential loading. *J Oral Biol Craniofac Res* 2013; **3:** 63–67.
43. Stankiewicz N R, Wilson P R. The ferrule effect: a literature review. *Int Endod J* 2002; **35:** 575–581.
44. Ferrari M, Vichi A, Fadda G M *et al.* A randomized controlled trial of endodontically treated and restored premolars. *J Dent Res* 2012; **91:** 72S-78S. 45. Fokkinga W A, Kreulen C M, Bronkhorst E M, Creugers N H. Up to 17-year controlled clinical study on post-and-cores and covering crowns. *J Dent* 2007; **35:** 778–786.
46. Al-Wahadni A, Gutteridge D L. An *in vitro* investigation into the effects of retained coronal dentine on the strength of a tooth restored with a cemented post and partial core restoration. *Int Endod J* 2002; **35:** 913–918.
47. Santana F R, Castro C G, Simamoto-Júnior P C *et al*. Influence of post system and remaining coronal tooth tissue on biomechanical behaviour of rootfilled molar teeth. *Int Endod J* 2011; **44:** 386–394.
48. Gegauff AG. Effect of crown lengthening and ferrule placement on static load failure of cemented cast post-cores and crowns. *J Prosthet Dent* 2000; **84:** 169–179.
49. Torbjorner A, Fransson B. A literature review on the prosthetic treatment of structurally compromised teeth. *Int J Prosthodont* 2004; **17:** 369–376.
50. Naumann M, Blankenstein F, Kiessling S, Dietrich T. Risk factors for failure of glass fiber-reinforced composite post restorations: a prospective observational clinical study. *Eur J Oral Sci* 2005; **113:** 519–524.

Official journal of the British Dental Association.