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# An evaluation of localized debonding between fibre post and root canal wall by finite element simulation

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## Abstract

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**Aim** To investigate the effect of localized bonding defects between fibre post and root canal wall on the stress distribution in the radicular dentine.

**Methodology** A tooth restored with a fibre post together with the alveolar bone were axisymmetrically modelled. A total of four models with localized debonding at the post to canal wall interface in different locations were analysed: Model A: perfect bonding layer over the entire interface; Model B: debonding at the cervical 1/3 of the interface; Model C: debonding at the mid 1/3; and Model D: debonding at the apical 1/3. A tooth restored without using a post was also included as the control (Model E). A load of 50 N was applied to the top of the full veneer cast crown at angles of 0, 15, 30, and 45° with the tooth's longitudinal axis. The stress distribution across the fibre post and root dentine was compared.

**Results** Higher stresses were generated in the radicular dentine as a function of the load angle. The differences in the stress distribution were negligible between the four models and virtually the same as that for model E (control).

**Conclusions** In this simulation, localized debonding at the fibre post to root canal wall interface, regardless of its location along the post, had little effect on the stress distribution in the root dentine.

**Keywords:** debonding, fibre post, finite element simulation, resin cement, stress distribution.

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## Introduction

Root filled teeth with extensive loss of coronal structure generally require post and cores to restore function. Fibre posts have been reported to present an elastic modulus closer to that of dentine when compared with cast posts and prefabricated metallic and ceramic posts, thereby allowing a relatively uniform stress distribution throughout the remaining root structure (Malferrari *et al.* 2003, Galhano *et al.* 2005). Among the various fibre materials available, lower modulus glass or quartz fibres seem to be the most suitable (Galhano *et al.* 2005), along with their white and translucent nature that can help ensure an aesthetic appearance to the restoration (Giachetti *et al.* 2004, Grandini *et al.* 2005).

With the introduction of endodontic fibre posts, new interest has been directed towards bonding them to the root canal wall using resin cements in combination with adhesive systems. Resin cements can increase retention (Mezzomo *et al.* 2003), tend to leak less than other cements (Reid *et al.* 2003), and provide at least short-term strengthening of the root (Mezzomo *et al.* 2003). A translucent fibre post can be used together with light-cure resin cements, although its ability to

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transmit light has yet to be determined. The use of dual- or self-cure composites to lute fibre posts has also been recommended (Ferrari *et al.* 2001). A study by Giachetti *et al.* (2003) showed no remarkable difference between the use of light-cure and dual-cure composites in the cementation of translucent posts.

However, achieving a good bond using resin cements is not a simple task. To minimize the contraction stress and ensure a reliable bond between root dentine and post, the resin cement should have a low conversion rate and, consequently, a low modulus of elasticity, while maintaining good mechanical resistance (Giachetti *et al.* 2004). The use of resin cements is more sensitive compared with most other luting cements, and requires extra steps, such as preparing the canal walls and placing a dentine-bonding agent. The predictable delivery of etchants and adhesive materials deep into the canal space can also be problematic. Unless these steps are performed quickly and carefully, some space may be generated between the post and the dental wall, thereby increasing the risk of a faulty bond at the post to root canal wall interface.

The presence of bonding defects, or debonding at the post to canal wall interface, might endanger the success of restoration. This is important from a biological viewpoint, because of the potential problem of leakage, while from a mechanical perspective, the presence of bonding defects can influence the mechanical behaviour of the post-restored tooth.

In this study, a post-restored tooth with debonded interface at various locations between the fibre post and the root canal wall were analysed with the use of finite element method. Primary concern was given to how the stress pattern in the root dentine near the fibre post changes as a function of the location of the debonded interface.

## Materials and methods

A mandibular first premolar, including the alveolar bone, was axisymmetrically modelled as presented in Fig. 1. All the important anatomical data, including the length and width of the crown, root and pulp canal, were referenced from the mesial aspect of the first premolar presented in a standard textbook (Ash 1984). The root canal was assumed to have been shaped to accommodate a commercially available fibre post. In the present study, the size 2 D.T. Light Post provided by Bisco Inc. (Schaumburg, IL, USA) was selected, which was 20 mm long with a double-tapered shape along its length from 1 mm in diameter at the apex to 1.8 mm at the coronal end.

The tooth restoration was modelled based on the following assumptions: the coronal part of the tooth structure above the cemento-enamel junction (CEJ) was totally lost, leaving only the root. Composite resin was used for the core build-up. The core, which was placed directly onto the dentine without any luting cement, had a height of 6 mm above the CEJ, so that it approached to approximately 1.5 mm below the occlusal plane, leaving space for the crown. A taper of 6° was placed on the wall of the core to retain a full veneer cast crown. A ferrule 1 mm in depth with a chamfer margin was designed around a band of root dentine below the CEJ. A 15 mm-long fibre post was designed to run from the very top surface of the 6 mm-high core down to 9 mm below the CEJ along the root. The remaining 4 mm at the apical part of the root canal, which was 13 mm long in total, was only filled with gutta-percha. A full veneer cast crown was modelled using a type IV gold alloy. The fibre post was cemented using resin cement with a thickness of 0.2–0.3 mm, thinner towards the apex.

Four different models were designed to represent the bonding quality at the interface between the fibre post and the root canal wall. Model A: a perfect bonding layer over the entire interface; Model B: debonding at the entire cervical 1/3 of the interface; Model C: debonding at the entire mid 1/3 of the interface; and Model D: debonding at the entire apical 1/3 of the interface. In addition to these four models, Model E, a tooth restored without a post, was also included as the control. Here, the root canal was filled entirely by gutta-percha. The coronal part of the fibre post as presented in Fig. 1 was replaced by core resin.

Geometrical modelling, finite element mesh generation and stress analyses were all carried out based on a linear elastic assumption using the NISA II/DISPLAY 3 program provided by EMRC (Troy, MI, USA). The NKTP 34 element, a quadratic element with eight nodes, was used throughout the finite element mesh modelling. The NKTP 34 element, and NKTP 37 element in NISA II, both have a special characteristic, as models built with these elements, which themselves are axisymmetric, also allow for nonaxisymmetric loading conditions. Thus, even though the geometry has to be axisymmetric, the vertical load that is parallel to the tooth axis and obliquely exerting loads can all be incorporated in the analysis. A representative of the finite element models used in this study consisted of approximately 2100 elements and 5400 nodes (Fig. 1).

 

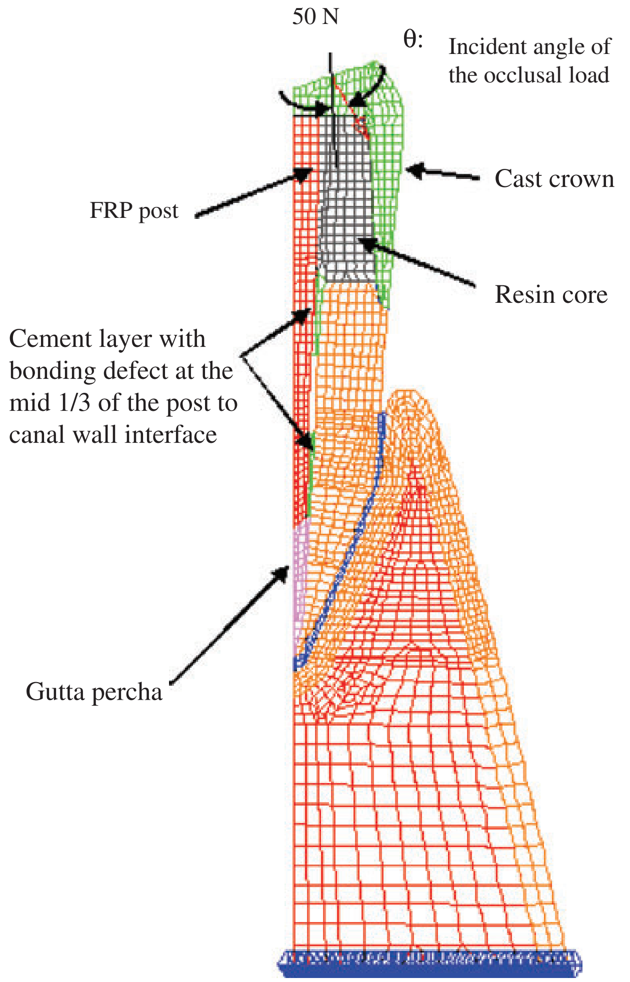


**Figure 1** Typical axisymmetric finite element model of mandibular first premolar restored with fibre post, core and full veneer cast crown, subject to oblique load of 50 N. A bonding defect or debond can be seen in the mid 1/3 of the post to canal wall interface.

As presented in Fig. 1, a 50 N static force was applied to the node located at the midpoint between the cusp tip and the central fossa. To simulate various loading conditions during mastication, loads were applied in oblique directions as well as the vertical direction. The three oblique loading directions were 15, 30 and 45° relative to the tooth's longitudinal axis.

Alveolar bone, 25 mm high, was also included in the finite element model. To secure the biologic width, the crest of the alveolar bone was set 3 mm down from the margin of the crown. Axisymmetric modelling of the three-dimensional alveolar crestal bone was artificially generated using a spline curve taking into account the differences in the bucco-lingual and mesio-distal configurations. The nodes on the bottom surface of the alveolar bone were fixed as the geometrical boundary conditions.

The bonding failure at the post to dentine interface was modelled based on removing the elements representing the resin bonding layer at the site that otherwise would have been present. The von-Mises stresses were evaluated at different locations in the root dentine near the fibre post, core, and gold crown. Figure 2 shows the stress monitoring points, i.e. the points where the nodal stresses were monitored, in the dentine along the fibre post, core, and gold crown at the nearest nodes in the dentine layer. The stresses were monitored at a total of 19 points. The stresses at the points on the right-hand side, B to J, were taken from the '0°' plane of the axisymmetric model, while those on the left, B to J, were taken from the '180°' plane. Table 1 summarizes the material properties used in the present study.

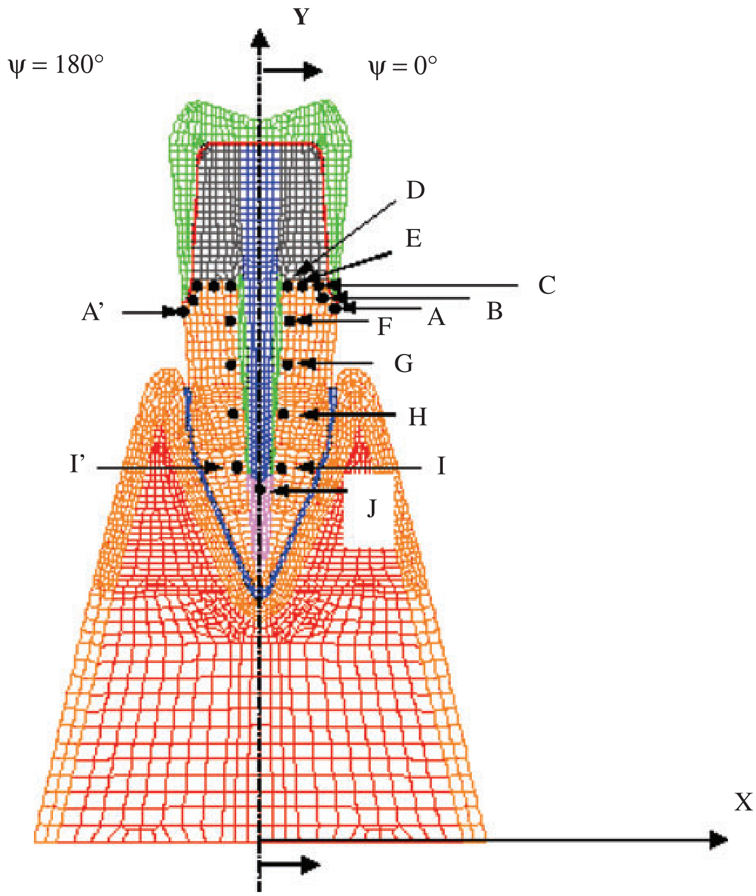


**Figure 2** Stress monitoring points (points A′ to I′ are on the left-hand side, i.e. $\psi = 180°$ plane, at the symmetric positions of points A to I w.r.t. $X = 0$ plane).

**Table 1** Material properties

| | Young's modulus (GPa) | Poisson's ratio | Reference |
|---|---|---|---|
| Dentine | 18.3 | 0.27 | Genovese *et al.* (2005) |
| Cortical bone | 13.7 | 0.3 | Ko *et al.* (1992) |
| Cancellous bone | 1.37 | 0.3 | Ko *et al.* (1992) |
| Periodontal ligament | 0.01 | 0.45 | Ukon *et al.* (2000) |
| Fibre post | 15.0 | 0.29 | [a] |
| Core resin | 13.8 | 0.3 | [b] |
| Gold alloy | 78.5 | 0.33 | [c] |

[a]Supplier's data from Bisco Inc. (Schaumburg, IL, USA).
[b]Average value from the data of Cohen *et al.* (1997) and Eldiwany *et al.* (1993).
[c]Supplier's data from Goodfellow Co. (Devon, PA, USA).

## Results

The typical result for the stress distribution is presented in Fig. 3, where Fig. 3(a) shows the overall von-Mises' equivalent stress based on the assumption of perfect bonding at the fibre post to root canal wall interface, subject to a vertical load of 50 N, while Fig. 3(b) is an enlarged view of the crown part. With the exception of the crown's occlusal part, higher stresses were concentrated.

For a more detailed comparison of the stress pattern, the stress results calculated for the 19 stress-monitoring points presented in Fig. 2 were plotted as presented in Figs 4–8. As such, each figure represents the stress in the dentine along the cast crown, core and fibre post for a particular model, subject to 50 N with different loading

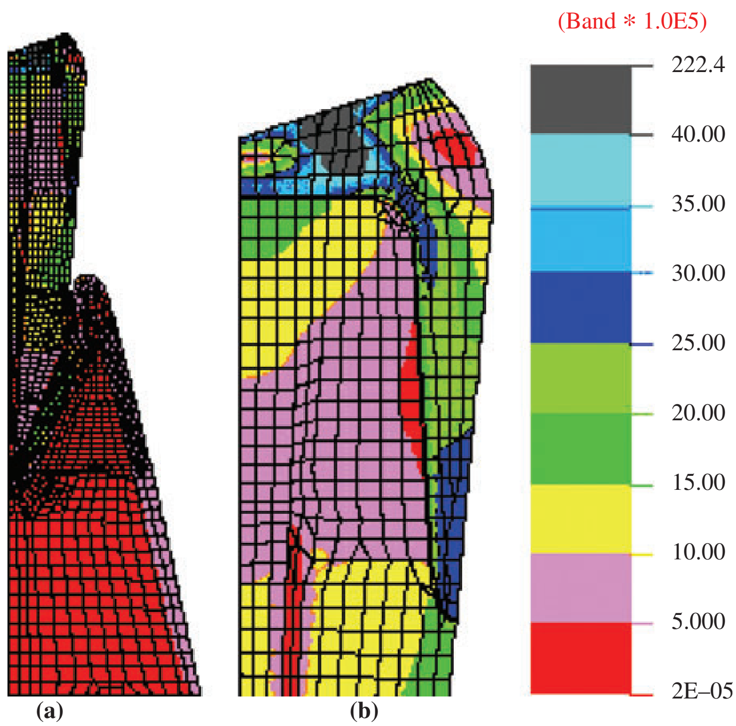


**Figure 3** Stress contour plots [von-Mises equivalent stresses in Pascal (N m$^{-2}$)] for Model A, subject to a vertical load of 50 N. (a) Overall stress and (b) stress across the cast crown.

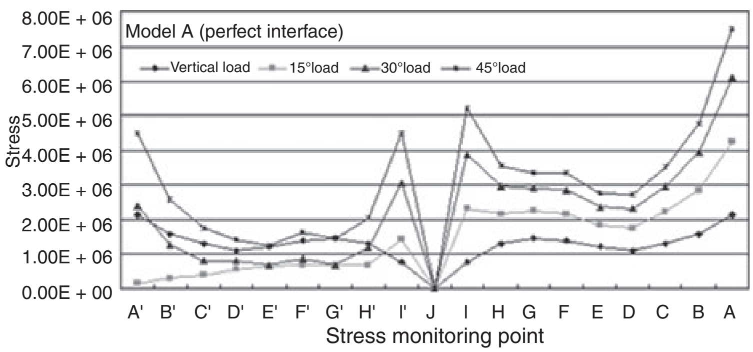


**Figure 4** The von-Mises stress in dentine along cast crown, core and fibre post for Model A, subject to four loading conditions.

directions. Thus, Fig. 4 corresponds to the stress data for Model A, while Figs 5–8 present the stress data analysed for Models B, C, D and E, respectively.

As presented in the figures, higher stresses were produced as a function of the angle of the occlusal load with the tooth's long axis. Under vertical load, stresses had a symmetric distribution in the right ($\varphi = 0°$) and left plane ($\varphi = 180°$). On the other hand, when the obliquely acting loads were applied stress distribution became asymmetric as the lateral component of the load produced bending moment. The bigger the angle of the load the bigger the bending moment, thus producing the increased level of stress. Stresses in the right plane, where both the external load and the bending moment produce compressive stresses, higher than those in the left plane. Stress plot in Figs 4–8 revealed almost the same pattern indicating that the geometrical conditions of the tooth–post-alveolar bone

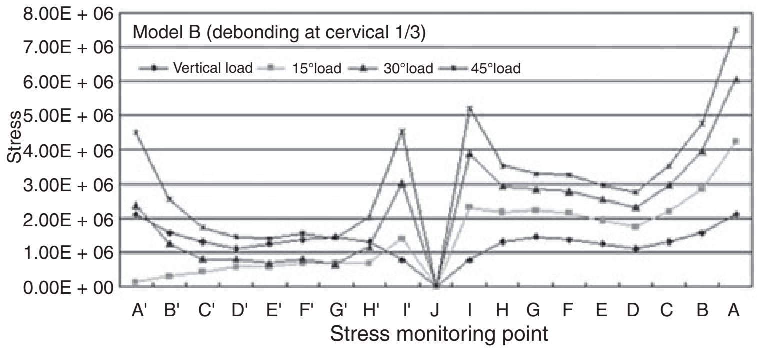


**Figure 5** The von-Mises stress in dentine along cast crown, core and fibre post for Model B, subject to four load conditions.

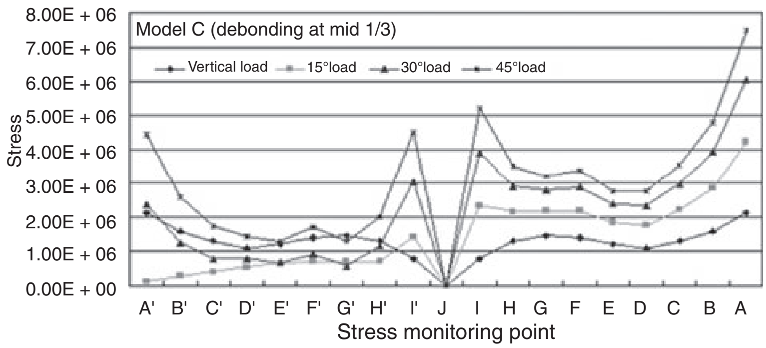


**Figure 6** The von-Mises stress in dentine along cast crown, core and fibre post for Model C, subject to four load conditions.

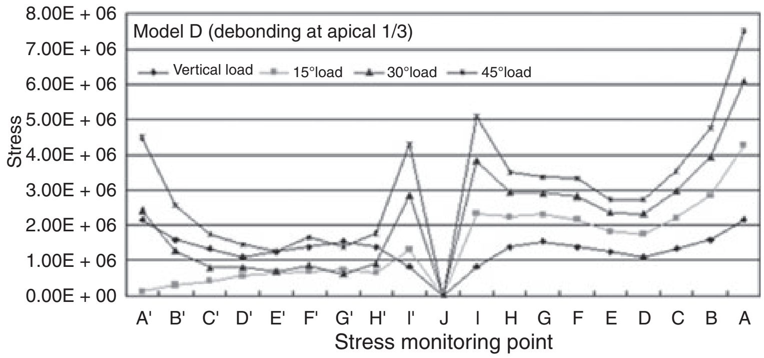


**Figure 7** The von-Mises stress in dentine along cast crown, core and fibre post for Model D, subject to four load conditions.

complex had a dominant affect over the debonded interface between the fibre post and the root dentine. Much lower stress was observed at the point 'J', i.e. set in the gutta-percha, compared with those obtained at other points set in dentine.

## Discussion

The manner in which a post is bonded to the root canal wall, i.e. the bonding quality, is important from both a biological and mechanical perspective. From the biological viewpoint, the bonding layer serves as a barrier to coronal leakage. Thus, from among the various cement materials, including resin, zinc phosphate and glass–ionomer cements, the resin cement looks more promising in this regard, as resin can bond with various types of posts, thereby allowing the dentine/resin/post to be joined via resin adhesion into one unit. A previous study by Bachicha *et al.* (1998) reported less leakage when using a resin cement with stainless-

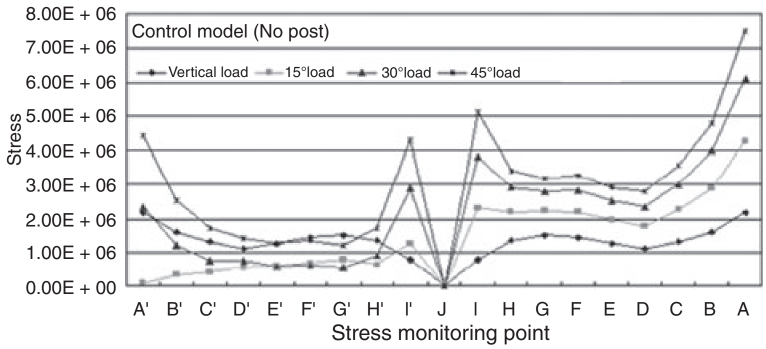


**Figure 8** The von-Mises stress in dentine along cast crown, core and fibre post for Model E, subject to four load conditions.

steel and carbon fibre posts compared with the use of a zinc phosphate or glass–ionomer cements. However, different resin systems have different sealing abilities. For example, fourth-generation adhesive systems (three-step systems) provided a better adhesive seal with root dentine than the more recent fifth-generation two-step systems (Mannocci *et al.* 2001), and Ferrari *et al.* (2001) recommended the use of self-cure or dual-cure cements because of limited light penetration into the root, even with translucent posts.

Meanwhile, from the mechanical viewpoint, resin cements also generally exhibit a better performance. For example, Saupe *et al.* (1996) emphasized their strengthening effect on roots with thin walls, while Junge *et al.* (1998) reported that posts cemented with resin were more resistant to cyclic loading than posts cemented with zinc phosphate and glass–ionomer cements. However, as resin is a technique-sensitive material, defects can easily develop as a result of unskilful handling, plus incomplete curing or a higher curing shrinkage can result in voids or bubbles. These defects in the bonding layer can then reduce the structural rigidity and create a larger free contraction surface area, contributing to a reduced contraction stress of the composite (Alster *et al.* 1992, Feilzer *et al.* 1993, Giachetti *et al.* 2004). Yet, because of the unpredictability in the void formation, resin cements are not always advantageous. In addition, voids impede the appropriate cementation of the post, resulting in debonding and a faulty bond. Therefore, as resin cements gain in popularity for the post restoration of a root filled tooth, the debonding, or faulty bonding, at the post to canal wall interface might remain an important issue.

Accordingly, the present study analysed the features of a faulty bonding layer using models with a bonding defect at different locations along the post. A series of stress analyses were then performed for each model, subject to loads of 50 N at various angles with the tooth axis.

The von-Mises' equivalent stress, plotted in Fig. 3 for Model A, showed a concentration in the dentine near the margin of the crown. It is worth noting that the higher stress here demonstrated that the load path at the crown margin played an important role in the transfer of the occlusal loads from the crown to the root dentine, thereby confirming the structural importance of the ferrule. Conversely, a uniform distribution of the stresses, without a noticeable concentration, was observed in the dentine along the fibre post and resin core, indicating that the load transfer from the fibre post to the root dentine was not significant. Meanwhile, the stress concentration at the top of the cast crown was an artefact as a result of applying the load at a single node instead of placing it in a distributed manner.

The stress results are quantitatively presented in Fig. 4, where the stress data at the 19 stress-monitoring points are plotted for four different loading conditions. As seen, the vertical loads produced an axisymmetrical stress distribution, meaning the stresses on the left-hand side (in the plane $\varphi = 180°$) and right-hand side ($\varphi = 0°$) were symmetric. However, under obliquely acting loads, the bending moment manifested itself as stress. Much higher stresses were developed as a function of the load angles. On the right-hand side, the stresses were amplified, as both the vertical and lateral components of the obliquely acting loads produced compressive stresses. Conversely, on the left-hand side, $\varphi = 180°$, the lateral load component produced tensile stresses instead, resulting in a relatively lower stress level. It is also worth noting that here too a severe stress concentration was observed in the dentine braced by the ferrule.

Figures 5–8 present the stress calculated for Model B, C, D and E, respectively. In general, virtually the same trends and levels of stresses were observed as in the case of Model A (Fig. 4).

Whereas the core provides the retention and resistance form for the final restoration, the post is meant to retain the core. It can be argued that the post should be designed to take-up more of the functional loads to relieve the stresses in the root dentine. However, in order to retain a core without violating the physiologic stress in the root dentine, as seen in a natural tooth, the post should not be allowed to carry or transfer functional loads into the root dentine. To this end, it is preferable to minimize the structural rigidity of the post to the level where it can just serve to retain the core under nonfunctional loads. The present study revealed that an fibre post served well for this design requirement when the tooth was subject to a vertical load.

When the functional load was at an angle with the tooth axis, the fibre post, placed at the root's central axis, i.e. the elastic axis, did not take up much of the bending moment or develop bending moment-induced stresses. As such, the dentinal stresses under oblique loading conditions were virtually unaffected whether or not the root was restored using a fibre post. This is clearly demonstrated when comparing the stress in Models A (Fig. 4) and E (Fig. 8), where the stresses are almost the same, revealing that the load taken up by the fibre post and load transferred from it to the root dentine were both negligible, regardless of the loading direction.

If a fibre post only takes up a small part of the load and no significant stress or load flows across the fibre post to canal wall interface, then neither the presence of bonding defects nor their location will have any effect on altering the dentine stress. Consequently, dentinal stress, which peaks in the apical part of the root and in the dentine near the ferrule, is not so much a function of the post as of the tooth and bone's anatomical conditions, i.e. the shape and physical properties of the root, socket bones, and/or cast crown. Not surprisingly, the stresses in Model B, C and D (Figs 5–7), where the post to canal wall interface had bonding defects, were virtually the same as in the cases of Models A and E. As a result, the present study demonstrated that the occurrence of a faulty bond at the fibre post to root canal wall interface did not have a detrimental effect as far as the stresses were concerned. Thus, it is not the stress but the microleakage problem that should be the primary concern in relation to bonding defects at the post to dentine interface. While the latter posses a direct threat to the long-term success of a post restoration, the debonded interface might exacerbate the problem. None of the current adhesive systems were capable of preventing microleakage over the long-term duration (Bouillaguet *et al.* 2000, Fabianelli *et al.* 2003).

Nonetheless, as differences in the structural rigidity of posts can change the load or stress flow at the post to dentine interface, the above findings should be cautiously reexamined when a post has different geometry or is fabricated from different materials.

## Conclusions

Within the limits of the present investigation, the following conclusions were drawn:

**1.** Although much higher stresses were developed as a function of the load angle, the differences in the stresses for the four models restored with fibre posts were insignificant.

**2.** The root dentine stresses were virtually the same whether or not the root was restored using a fibre post.

**3.** A faulty bond at the fibre post to root canal wall interface was not found to have a detrimental effect as far as the stresses were concerned.

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