

Is the glass half empty or half full? A novel “philosophical” approach to the “mystery” of the so-called ferrule effect



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ABSTRACT

The prognosis of endodontically treated teeth has traditionally been associated with the presence of the so-called ferrule effect that is generally related with the presence of a minimum of 1–2 mm of sound tooth structure at the cervical area of parallel axial walls that totally encircle the tooth. Even though all of these factors are well desired, one should question if their absence should condemn a tooth and compel extraction as the only logical treatment plan option.

For this reason an hypothesis is being formed that associates the aforementioned factors not with the presence of the so-called ferrule effect, but rather with the resistance form of the preparation that is being provided by the sound tooth structure at the cervical area of the tooth. When the desired resistance form is provided by sound tooth structure of endodontically treated teeth, then less lateral forces are being transferred to the post & core and subsequently to the root of the teeth, thus minimizing the chances of decementation of the post & core or worst fracture of the root.

Even more important, if this hypothesis may be further entertained, then even when the so-called ferrule effect is not present, the teeth may not be extracted, but alternative strategies for post & core restorations may be investigated, such a more flexible carbon- or glass-fiber posts & core build ups made from flowable resin composite that may accommodate for the increased lateral forced exerted to the post & core complex during function.

Introduction

The restoration of endodontically treated teeth has troubled dentists for decades [1–6]. Long before the invention of modern rotary instruments and the evolution of highly effective prosthetic solutions, the most commonly used technique for restoring damaged teeth was a post-retained build-up with a crown placed either on top, or integrated with the post as proposed by Richmond. As posts on roots were routinely used as abutments for single crowns and fixed partial dentures, the dentists soon observed that the longevity of these restorations correlated with the amount of the existing tooth structure at the cervix of the tooth. The logical assumption that was made was that the part of the crown that surrounded the existing tooth structure acted as ring that reinforced the tooth and protected it against fracture. Thus, the term “ferrule” emerged in the dental literature [7,8]. This term is found in the glossaries of both specialties associated with the restoration of endodontically treated teeth. In the 8th Edition of the Glossary of

Prosthodontic Terms [9] the term ferrule is listed as “1: a metal band or ring used to fit the root or crown of a tooth (Fig. 1A) and 2: any short tube or bushing for making a tight joint”. In the 9th Edition of the Glossary of Endodontic Terms [10] the term ferrule is listed as: “a band or ring of restorative material surrounding the crown or root of a tooth to provide strength”. The terminology found in both of the aforementioned glossaries are dental adaptations of the meaning of ferrule that can also be found in other dictionaries, where it is stated that: “A ferrule (a corruption of Latin viriola “small bracelet”, under the influence of ferrum “iron”) is any of a number of types of objects, generally used for fastening, joining, sealing or reinforcement. These are narrow circular rings made out of metal, or less commonly, plastic. Ferrules are also often referred to as eyelets or grommets within the manufacturing industry. Most ferrules consist of a circular clamp used to hold together and attach fibers, wires, or posts, generally by crimping, swaging, or otherwise deforming the ferrule to permanently tighten it onto the parts that it holds”.

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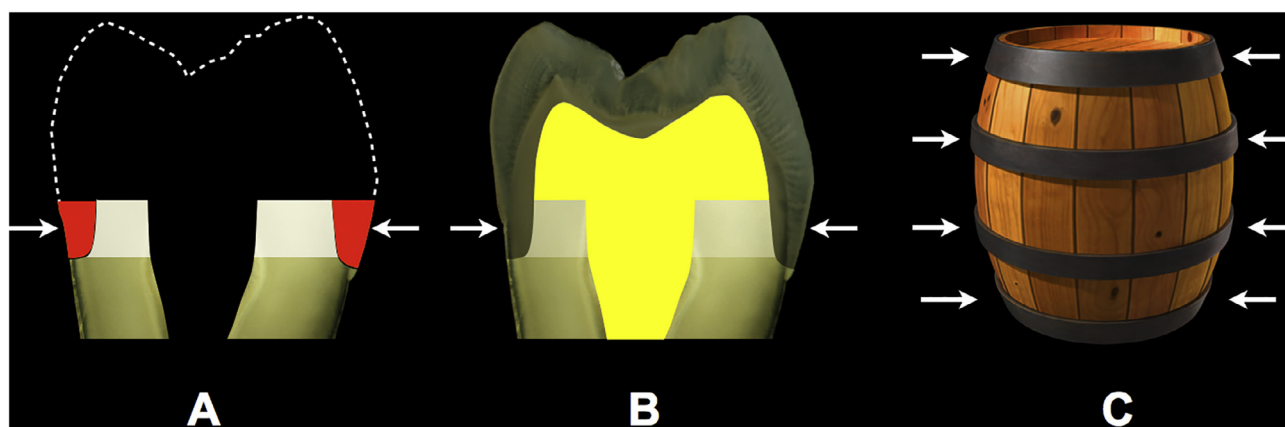


Fig. 1. (A) Schematic representation of ferrule described as “a metal band or ring used to fit the root or crown of a tooth”, (B) Schematic representation of crown placed on an endodontically treated tooth that has been restored with a post and core and that the remaining tooth structure fulfils the criteria of the so-called “ferrule effect”, C. Schematic representation of a barrel where the metal hoops encircle and truly bound together the wooden staves of the barrel.

It is commonly acknowledged that endodontically treated teeth that are structurally damaged are preferably restored with crowns. In that case, the dental literature is abundant with research that supports the so-called “ferrule effect” [11–19] that is claimed to reinforce the root-filled teeth, increase their resistance to fracture and protect them against the wedging effect of a tapered post and the lateral forces during post insertion. In general terms, the ferrule should (1) be a minimum of 1–2 mm high, (2) have parallel axial walls, (3) totally encircle the tooth, (4) end on sound tooth structure, and (5) not invade the attachment apparatus of the tooth (Fig. 1B).

Questioning the ferrule effect

Even though all of the above seem sensible and there can be no claims to argue the benefits of tooth structure at the cervix of the tooth, one may wonder about the true function of the tooth structure coronal to the margin of prepared tooth. Does its presence really serve the “ferrule effect” provided by the crown? Or could it be something else? One of the most common comparisons used to explain the ferrule effect is the metal hoops that encircle and bound together the wooden staves of barrels (Fig. 1C). If these metal hoops were not present, then the wooden staves would separate, due to the hydrostatic pressure of the liquid contained inside the barrel. Even though this has been proved irreplaceable in the case of barrels, there is little evidence to document the increased internal pressure in the case of endodontically treated teeth. The hydraulic pressure exerted by the luting cement during the cementation of posts may be of significant magnitude [20,21] (dependent on many factors, such as the viscosity of the cement, the speed of insertion, the space between the root and the post and provision or not of venting of the cement), but the crown has no way to protect the tooth from fracturing as a ferrule during the cementation of the post, unless the crown is in one piece with the post, like in Richmond crowns that are hardly ever recommended nowadays.

After the cementation to the crown, the increased internal forces in endodontically treated teeth are attributed to the wedging effect of the post during mastication, which the ferrule is claimed to counteract [22,23]. Even though this is plausible, one can only wonder about the mechanics of such a preventive mechanism. Wedging forces that are caused by vertical occlusal forces are mainly offset by the tooth structure on the occlusal part of the prepared teeth and not by tooth structure at the axial walls. It is the thickness of dentin, especially on the top flat part of the axial walls that resists the wedging action of the post & core. The height of the axial walls does not seem to mechanically contribute to the resistance against vertical wedging forces, except that it is common sense that increased height of axial walls corresponds to more tooth structure that contributes to the strength of the tooth.

Lateral occlusal forces do exert stresses to the post & core, which may fracture the tooth. Nevertheless, these lateral wedging forces do not act homogeneously on all the internal walls of the root where the ferrule could have been helpful in protecting against fracture, but rather as a nail that is being hammered against one side of the dentinal root walls, where the ferrule is far less effective in preventing possible tooth fracture.

In case there is no tooth structure above the margins and crown lengthening or orthodontic extrusion are not viable options, should the teeth be condemned to extraction, as the roots of the tooth are doomed to be fractured, over time, by the posts inserted in them? Before investigating what needs to be done, when there is little or no tooth structure available and crown build up – with or without a post & core – is necessary, it is essential to understand what is important in preparations of intact teeth, with no caries or endodontic treatment. Thus, an unconventional way to discuss the purpose of tooth structure coronal to the margin of prepared endodontically treated teeth and consequently the real meaning of the so-called ferrule effect is to examine some basic aspects of prepared teeth, such as the retention and resistance form.

Alternative hypothesis

Retention form refers to the features of a tooth preparation that resist dislodgment of a crown in a vertical direction or along the path of placement [9]. Resistance form refers to the features of a tooth preparation that enhance the stability of a restoration and resist dislodgment along an axis other than the path of placement [9]. Both of these properties are highly associated with the angle of convergence between the opposing prepared axial surfaces and the incisocervical/occlusocervical dimension of preparations [24,25]. The ideal convergence angle of axial walls is between 2 and 6 degrees, even though larger angles are commonly encountered. The minimal incisocervical/occlusocervical dimension of anterior teeth and premolars is 3 mm [26]. This dimension is increased to 4 mm in molars, as they are usually prepared with greater convergence, have greater diameter, and are located in areas with greater occlusal forces. As far as resistance form is concerned, it has been demonstrated that it is crucial for the axial walls to have the least convergence at the cervical third of the preparation.

Keeping all of the above in mind it is not difficult to visualize the “ideal” preparation. It should have axial walls as parallel as possible – especially at the cervical third – and it has to be as high as possible, in any given clinical circumstances around 4.5–6 mm. As mentioned before it is the cervical third of the preparation that it is crucial for the resistance form. Taken into consideration that the ideal preparation height is 4.5–6 mm, a cervical third of 1.5–2 mm with parallel axial

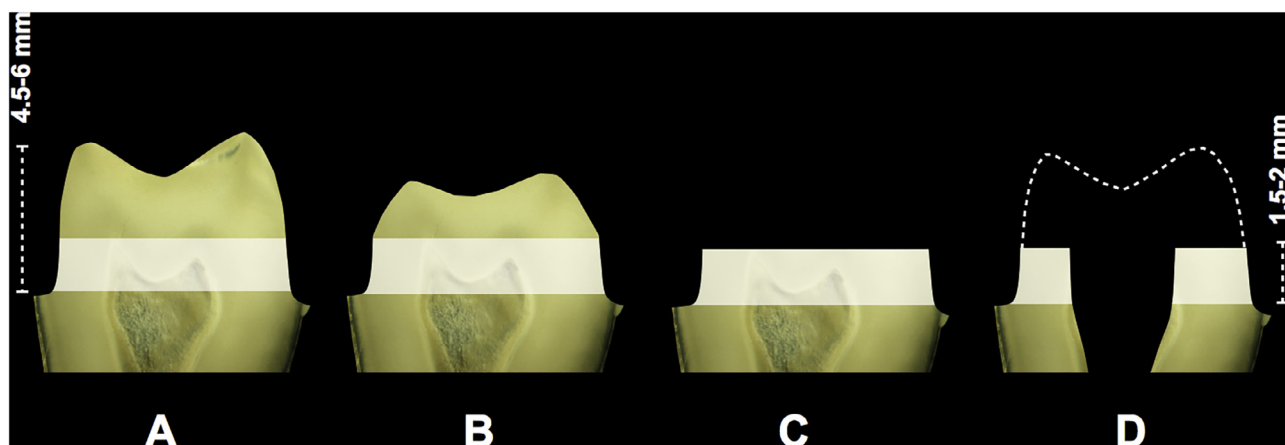


Fig. 2. (A) Schematic representation of ideal preparation with adequate resistance form and retention (height and convergence of axial walls). (B) Schematic representation of less than ideal preparation with adequate resistance form (parallel axial walls at the cervical third) but not ideal retention (decreased height and convergence of the upper half axial walls). (C) Schematic representation of much less than ideal preparation with adequate resistance form (parallel axial walls at the cervical third) but much less than adequate retention (total absence of axial wall coronal to the bottom third of an ideal preparation). (D) Schematic representation of an endodontically treated tooth where the middle and upper thirds of an ideal preparation are missing, but there is enough tooth structure on the cervical third, providing adequate resistance form or the so-called “ferrule effect”.

walls should provide adequate resistance form to the preparation (Fig. 2A). Even though the convergence of the axial walls is dependent on various factors (i.e. teeth are commonly prepared with greater convergence in clinical situations like posterior compared to anterior, mandibular compared to maxillary and fixed partial denture abutments compared to individual crowns), it can be kept to a minimum when the clinical circumstances impose to the clinician to exert extra caution. If the tooth structure in the middle and coronal third has less than ideal convergence (Fig. 2B), it is certainly not something that the clinician aims for. But if this is the case, then the consequences are of less importance, as far as the resistance form of the preparation is concerned. The extreme situation of such a hypothetical situation where the cervical third of preparation remains ideal and the middle and coronal gradually deteriorate would be the situation where the two upper thirds completely disappear and only the cervical third remains intact (Fig. 2C). Such a situation is purely hypothetical, as if that was the case the cervical third would not be named the cervical part but it would represent the whole height of the preparation and it would certainly not be sufficient as far as the minimal incisocervical/occlusocervical dimension and the retention form would not be sufficient. Nevertheless, just for argument's sake, if sound tooth structure was present at the cervical 1.5–2 mm of the preparation then the clinician could build the abutment to reach the optimal 4.5–6 mm in order to obtain the necessary height of the preparation that would ensure the necessary retention form. In the amalgam era, such a task was quite difficult to accomplish. In the adhesive era of resin composites, such a task is not inconceivable, but rather within the capabilities of effective dentin bonding systems. In such a clinical situation, the retention would mainly be attributed to the dentin of the cervical third and the retention to the resin composite of the middle and coronal third. Even though all of the above mentioned seem rather reasonable for vital teeth, when endodontically treated teeth are to be treated, there is a tendency to forget the advantageous aspects of adhesive dentistry and concentrate on the mechanical aspects of prosthodontics that has been passed from generation to generation, ever since the 18th century, when Pierre Fauchard, the father of modern dentistry, published *Le Chirurgien Dentiste* (“The Surgeon Dentist”) in 1728.

If there is an endodontically treated tooth with 1.5–2 mm of nearly parallel axial walls of sound tooth structure coronal to the margin, then this would correspond to the “ideal” cervical third of an abutment, in which the middle and coronal thirds are “unfortunately” missing (Fig. 2D), and a crown build up – with or without a post – is considered

mandatory. Even though the clinical parameters of the build up have been thoroughly investigated, an unanimous consensus has yet to be reached. Regardless of the technique used for the build up, after the abutment has been reconstructed, if one were to examine the areas of the preparation that mainly contribute to the retention and resistance form, it is rather obvious that the cervical third, of sound tooth structure, mainly renders resistance, while the reconstructed middle and coronal thirds are mainly responsible for the retention form, in a similar manner to the aforementioned hypothetical vital abutment.

To recapitulate, the hypothesis involves an endodontically treated tooth, which if one would like to elaborate more thoroughly on the properties of the sound tooth structure coronal to the margin, it could be claimed to: (1) be a minimum of 1.5–2 mm high, (2) have parallel axial walls, (3) totally encircle the tooth, (4) end on sound tooth structure, and (5) not invade the attachment apparatus of the tooth. But, isn't this identical to the so-called ferrule effect? In one sense, yes. The coronal third of the hypothesized endodontically treated tooth has exactly the same properties of an endodontically treated tooth that fulfills the requirements to be restored with a crown that would provide the so-called ferrule effect. On the other hand, the fact that this sound tooth structure is not there for the crown to “grasp” on it, in order to provide the so-called ferrule effect, but rather than to provide resistance form to the preparation, given by the sound tooth structure and not by the build up, significantly differentiates the clinical approach towards endodontically treated teeth (Fig. 3).

The philosophical question “is the glass half empty or half full” seems to be applicable in such a hypothetical case. Should a given clinical situation be a cause for optimism (half full) or pessimism (half empty) or as a general test to simply determine an individual's point of view? The pessimistic approach would be that if there is less than ideal tooth structure available for a so-called ferrule effect to be achieved, then the tooth cannot be properly restored and should be extracted, as there is no miracle solution to recreate sound tooth structure that would enable the desired so-called ferrule effect of the crown used to restore the endodontically treated tooth. The optimistic approach would be that if there is less than ideal tooth structure available to provide the desired resistance form, then one should seek alternative ways in order to achieve the desired resistance form with the build up and investigate solutions to deal with the problems that are associated with the fact that retention is not mainly provided by sound tooth structure but also by the build up. The clinical approach towards endodontically treated teeth could be considered as the ultimate litmus test that determines the

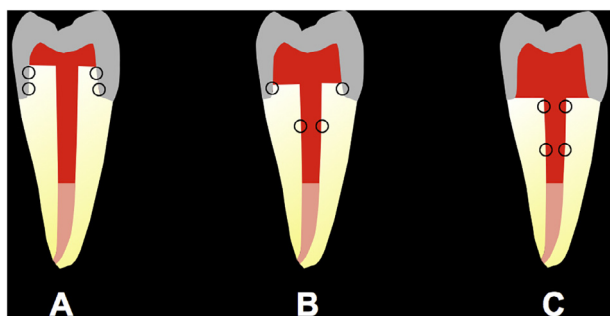


Fig. 3. Schematic representation of endodontically treated teeth restored with crown and post & core in cases where there is varying degree of existing tooth structure coronally to the margin of the preparation. (A) Enough tooth structure to provide resistance to lateral forces, so little if any lateral forces are being transmitted to the root, (B) Not enough tooth structure to provide resistance to lateral forces, so part of the lateral forces are being transmitted to the root of the tooth, (C) Total absence of tooth structure to provide resistance to lateral forces, so all the lateral forces are being transmitted to the root of the tooth.

clinician's point of view and belief towards biomimetic adhesive dentistry.

Alternative solution

If the worst-case scenario is present and there is no tooth structure available, a crown placed on a post & core build up with no ferrule effect is doomed to fail, according to the pessimistic scenario. If one is to pursue the optimistic scenario then he should carefully plan the materials and technique used for the build up, in order to achieve the optimum longevity of the restoration. If there is no tooth structure available coronal to the margin of the restoration (Fig. 4A), the use of an intraradicular post is mandatory for the retention of the build up material. Even though many clinicians would prefer a custom-made cast post & core, there are reasonable doubts on this choice, as all the lateral forces will be directly exerted via the crown to the post & core and inadvertently transferred via the cement interface to the root of the

tooth [27,28]. Thus, if the forces are greater than the threshold of the root – cast post & core – crown complex, then it is inevitable for the weakest link of the complex to “break”. The extracoronal part of the complex very rarely fails. Porcelain fractures in the veneering material of the crown may be observed, but crown or core fractures, or decementation of the crown from the core build up are rarely – if ever – observed. Bending or fracture of the post is also quite scarce. On the other hand breaking of the cement, which would lead to decementation of the post & core in one piece with the crown is often observed. This is due to the fact that as there is no resistance provided by extracoronal dentin, the lateral forces exerted to the crown are transferred via the post to the adhesive interface of the post, and this will gradually cause the breakage of the cement and the decementation of the post & core – crown complex, describing the best case scenario of failure. If the cement is strong enough and does not break, then the forces are directly transmitted to the dentinal walls of the root and a root fracture is the catastrophic outcome. It is often witnessed by the clinical reality that the solutions proposed by research that favored “strong” materials may sometimes lead to catastrophic failures [29–31], which would confirm the pessimistic scenario, as was often the case with Richmond crowns with no ferrule effect.

Even though there are similar tales in many cultures, in ancient Greece, it was Aesop who is credited with the fable about the Oak and the Reed, with the contrasting behavior of the oak, which trusts in its strength to withstand the storm and is blown over, and the reed that ‘bends with the wind’ allowing it to survive. Even if tales are more often told to children than dentists, one cannot resist the temptation, when observing endodontically treated teeth, of paralleling oaks with periodontally healthy teeth that are being mechanically “strengthened” with post & cores and crowns and reeds with periodontically involved teeth with increased mobility. One irrefutable clinical observation is that the latter scarcely – if ever – fracture. So if the tooth is periodontally healthy, could “softening” something in the root – post & core – crown complex concur to “absorb” some of the forces and obviate the catastrophic scenario of root fracture?

If such a scenario were to be investigated, the first step would be to select a more elastic material for the core build up [32]. For this

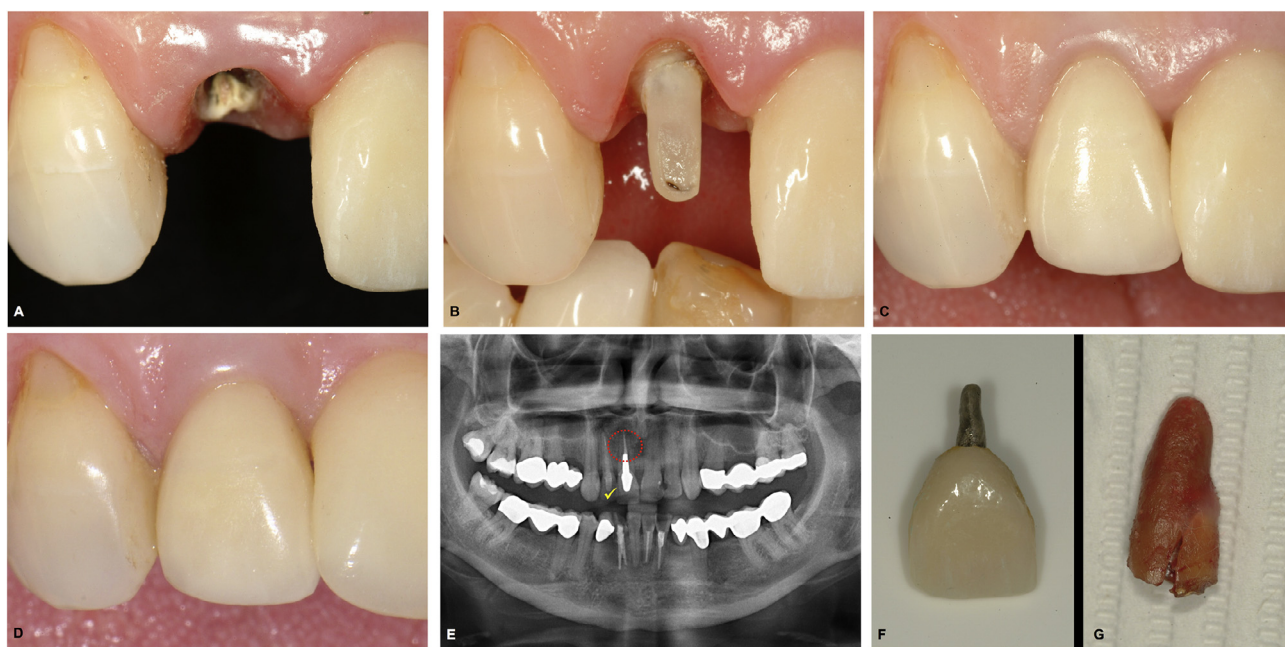


Fig. 4. (A) Tooth with no tooth structure available coronal to the margin of the preparation. (B) Crown build up, using glass-fiber post and flowable resin composite. (C) All ceramic crown cemented on the glass-fiber and flowable composite build up. (D) 10-years recall, with the all ceramic crown in contact in maximum intercuspation. (E) 6 year after placing the post & core and all ceramic crown the patient experienced an elbow hitting accident. (F) The adjacent central incisor that had a metal post & core suffered a vertical fracture of the root that caused the extraction of the tooth and the restoration with an implant supported crown (G).



Fig. 5. (A) Lateral incisor with total absence of tooth structure coronally of the margin of the preparation. (B) Build up using glass-fiber post and flowable resin composite. (C) Metal ceramic crown cemented on the glass-fiber and flowable composite build up. (D) 7 years after placement the patient presented with a horizontal fracture of the crown and the post & core. (E) The patient presented with severe wear on the palatal part of the upper anterior natural teeth. It may be hypothesized that the porcelain on the palatal side of the crown did not wear in a similar fashion as natural teeth did and gradually more lateral forces were being exerted on the palatal side of the lateral incisor, thus resulting to the horizontal tooth fracture. Nevertheless, even though the post & core fractured, the root of the tooth did not break and it was possible to restore the tooth with a new glass-fiber and flowable composite build up and a crown.

purpose, a suitable choice would be a flowable resin composite, which mechanical characteristics are actually closer to that of dentin, and in that sense it is surely a better choice from a biomimetic point of view, than regular resin composite, amalgam or gold, which mechanical characteristics more closely resemble these of enamel. Even though the category of flowable resin composites contain a variety of materials

with diverse formulations and percentage of inorganic fillers, it is quite an easy and fun clinical task to find a flowable resin composite that when drilled, it gives the same “feeling” like the adjacent dentin, and thus act in a biomimetic way. Flowable resin composites have the drawback of higher polymerization shrinkage [33], but when the flowable composite is placed around the post and polymerized, the

polymerization shrinkage, in such a case, is favorable [34] (even though this is hard to believe), as it helps the flowable resin composite adapt better around the post, as it flows from the outer free surfaces of the bigger periphery of the build up, towards the bonded smaller inner periphery around the post. Even though the necessary research has yet to be done, if such a “weaker” restorative material is used for the construction of the core, a “dampening” effect of the occlusal forces might also be observed.

In order to further diminish the transmittal of lateral forces that cannot be absorbed by the non-existent cervical extracoronary dentin and are transmitted to the post & core, the use of nonmetal posts should also be considered [35] (Fig. 4B). Cast post & cores are made from metals that are isotropic materials that transmit forces uniformly in all orientations and thus towards the root. On the other hand, carbon- and glass- fiber posts are anisotropic [36] materials that resist forces exerted vertical to their long axis, which is helpful in order to counteract lateral forces that are amplified when there is no extracoronary dentin to provide resistance form, while they transmit less stress along their long axis [37,38] (something that is also useful, in order to transmit less forces to the root of the tooth) (Fig. 4C–G).

Even though the aforementioned properties of fiber posts are confirmed by research, many dentists are skeptical to use the “weak” and “flexible” posts, as they consider that they do not “strengthen” the teeth [39]. It is true that when “weaker” carbon- or glass-fiber posts are used, it is possible for them to break under high occlusal stresses. Clinical observations confirm this, when “weaker” posts fracture at the top coronal part of the root, where the lateral forces are exerted, when there is no resistance form provided by the non-existent extracoronary dentin. In such a case it is the build up and crown that are “decapitated” from the root, which remains intact, with no fracture (Fig. 5A–D). Even though this scenario is not welcome, it is preferable to the catastrophic scenario of root fracture caused by “strong” posts. The Hippocratic Oath includes the promise “to abstain from doing harm”, which is one of the principal precepts of bioethics that all healthcare students are taught in school and then follow as a fundamental principle in their clinical practice. From that point of view, the restoration of endodontically treated should follow a technique that is the least likely to harm the roots of the teeth [40–42] (Fig. 5E).

Even though the mechanical approach of traditional prosthodontics quite often favored strong restorative solutions [43–45], it is wise to remember that in the very first era of modern dentistry, Pierre Fauchard used for the cementation of posts a heat-softened adhesive called “mastic”, which is a resin obtained from the mastic tree (*Pistacia lentiscus*). The word mastic derived from the greek verb “μαστιχεν” (mastichein), which means “to gnash the teeth” and is the source of the English word masticate. In Greece, it is known as the “tears of Chios,” being traditionally produced on that Greek island and it has been chewed since ancient times, a habit that grew popular over the years and thus the word mastic became a synonym for gum in many languages. It is obvious that the pioneers of modern dentistry had made provision for an “elastic cushion” in the root – post & core – crown complex, a suggestion that could also be useful today, when restoring structurally compromised endodontically treated teeth, with no so-called ferrule effect.

Conclusions

To conclude, the use of adhesively luted carbon- or glass-fiber posts and core build ups made from flowable resin composite might be the best clinical choice when there isn't 1.5–2 mm of dentin coronal to the margin, that would provide resistance form to the preparation given by sound tooth structure. In such unfavorable clinical situations, increased lateral forces are exerted via the post & core build up to the root of the tooth, and even though with the aforementioned technique there is a slight chance of breakage of the “weak” post & core build up, the fracture is far more likely to be extracoronary and a catastrophic non

restorable root fracture is almost certainly being avoided.

Conflict of interest

Authors declare that there is no conflict of interest.

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