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Modern Endodontic Principles Part 7: The Restorative Interface

Abstract: The restoration of endodontically-treated teeth is a topic that has been extensively studied and yet remains controversial. The endodontically-treated tooth can be restored with a wide range of techniques of varying complexity. This article reviews the literature on this topic. Consideration is given to the ferrule and its importance in achieving success. Furthermore, consideration will be given to the use of endodontically-treated teeth as abutments for fixed and removable prostheses and the challenges this presents. Clinical recommendations are presented as guidelines to improve the predictability and outcome of treatment when restoring structurally compromised root-filled teeth.

CPD/Clinical Relevance: The prognosis of endodontically-treated teeth depends not only on the success of the endodontic treatment, but also on the type of reconstruction.

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Following successful endodontic therapy the tooth must be restored. This restoration process has several justifications:

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- To provide a coronal seal;
- To restore form, occlusal stability, and adequate contact points with the adjacent teeth;
- To restore function;
- To protect the residual tooth structure against further tissue loss;
- To ensure health of the marginal periodontal tissues;
- To provide optimal aesthetics.

Of these functions, protection of the underlying tooth structure should be recognized as essential in preventing endodontic failure. It is known that the longevity of a root-treated tooth is directly related to the amount of remaining sound tooth material¹ and there is frequently extensive loss of natural tooth structure in endodontically-treated teeth.² Previous beliefs that the mechanical weakening of endodontically-treated teeth was due to the difference in moisture content when compared to vital teeth has been disproved.³ It has been shown that endodontic access and treatment only reduces the stiffness of teeth by 5%, compared to a 63% reduction

in stiffness following preparation of an MOD cavity.⁴ It is now accepted that cuspal deflection and thickness of the residual walls and cusps are more important factors. As cavity size increases, especially after endodontic access, and the marginal ridges are lost, structural stability decreases. Thus, the presence of a marginal ridge is now considered a far more influential factor upon tooth strength than an endodontic access cavity.⁵ However, it must be noted that non-vital teeth do appear to have reduced tactile sensitivity and therefore have the potential to be loaded to a greater degree before the biofeedback mechanism is initiated.⁶

Direct restoration

If the coronal structures are largely intact (particularly marginal ridges) and loading is favourable, a simple plastic restoration can be placed in the access cavity. Placing a bonded restoration immediately following obturation whilst the rubber dam remains in place is good practice (Figure 1).

The core

Core is the term used to describe a restoration that is placed in order to build up a broken down tooth before receiving an indirect restoration. The role of a core is reliant upon how much coronal dentine remains. For the majority of pulpless teeth a structural core material is required as this will form the bulk of the final preparation. Consequently, it will be subjected to significant functional stresses and must therefore exhibit adequate mechanical properties to resist these. There are essentially four types of direct core material available:

1. Amalgam;
 2. Resin composite;
 3. Glass ionomer; and
 4. Hybrid materials, ie resin-modified glass-ionomer cements (RmGIC).
- The relevant properties of these are summarized in Table 1.

Endodontically-treated teeth typically lack sufficient coronal dentine in which retentive features can be prepared to retain a core without compromising the strength of the remaining tooth structure. Where a large pulp chamber exists, extension of amalgam/composite into this space alone may be sufficient. Where the pulp chamber is small or there is more significant tooth loss, the Nayyar technique should be used: 2–3 mm of the coronal root filling is removed and an amalgam or composite core placed to fill the coronal preparation, the pulp chamber and the extension into the roots (Figure 2). This technique has been widely adopted for premolars as well as molars and a core of this type will function well even when there is as little as one sound cusp remaining. Given bonded cores do not require additional retentive features, clinicians should consider resin composite cores, where possible, to preserve tooth structure.

Ferrule

A key component in the predictability of restoration of endodontically-treated teeth is the 'ferrule'. The ferrule is that part of the crown that encircles the remaining tooth structure (Figure 3). The ferrule binds the remaining tooth together, simultaneously preventing

Amalgam	■ Proven track record ■ Retentive features require additional preparation ■ Good contrast with tooth substrate hence easy to prepare ■ Cannot usually be prepared at same visit (newer high copper alloys may be prepared after short delay) ■ Cannot be bonded to tooth without resorting to intermediary products
Resin Composite	■ Bonding negates the need for additional retentive features ■ Crown preparation can be commenced immediately ■ Difficult to differentiate from tooth tissue (some 'core composites' have contrasting colour) ■ Technique sensitive ■ Chemical/dual cure undergo greater discoloration (due to tertiary amine activator) and should be used with caution where aesthetics is critical ■ Water sorption and expansion means impression taking should be delayed following preparation
Glass Ionomer and RmGIC	■ Bonds to dentine ■ Release fluoride ■ Water sorption and expansion higher than resin composite ■ Inherently weak ■ Long-term behaviour of materials not well documented Not suitable as a structural core material but may be used to remove undercuts

Table 1. Properties of core materials.



Figure 1. Elective endodontics was performed on LR6 to allow internal access to an external cervical resorptive lesion. With sound coronal tooth tissue including intact marginal ridges, the clinician can have confidence in the long-term success of direct plastic restoration with composite.

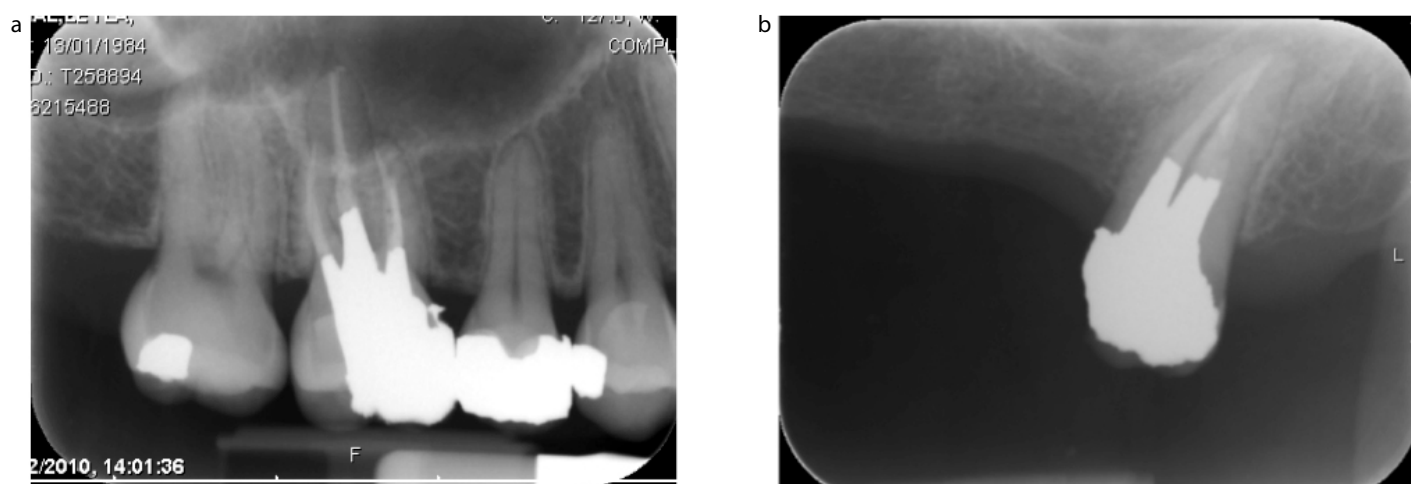


Figure 2. (a, b) Following endodontic treatment, removal of the coronal 3 mm of GP from the canals and the placement of a Nayyar core in amalgam or composite provides both excellent coronal seal and a sound foundation for future indirect restoration.

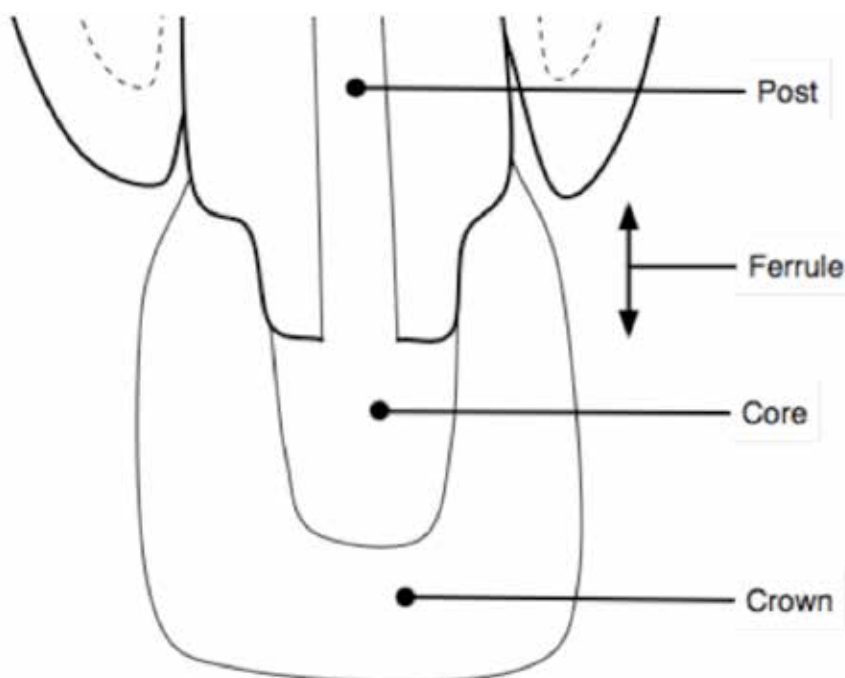


Figure 3. The ferrule is that portion of the crown that encircles the remaining dentine.

root fracture and providing resistance form to prevent dislodgement of the crown during function⁸ (Figure 4). Four factors which directly influence the ferrule have previously been identified.⁹

1. Ferrule height

The greater the height of remaining tooth structure above the margin of the preparation, the

better the fracture resistance provided. A ferrule height of 2 mm or more is predictive of improved outcomes.¹⁰

2. Ferrule width

Clinically, it is generally accepted that walls are considered 'too thin' when they are less than 1 mm in thickness, such that the minimal ferrule height is only of value if the remaining dentine has a minimal thickness of 1 mm.¹¹

3. Number of walls and ferrule location

Although studies have demonstrated the superiority of a uniform full 360° ferrule over one that varies in different parts of the tooth, the concept of a partial ferrule should not be ruled out.¹² Having a good palatal ferrule only on upper incisors is as effective as having a complete 'all around' ferrule, as this will resist the forces applied in function to the palatal surface.¹³

4. Type of tooth and the extent of lateral load

Lateral forces have a greater potential to damage the tooth-restoration interface when compared with vertical loads.¹⁴ Hence, a differential approach needs to be adopted when it comes to the restoration of anterior and posterior teeth.

If there is no ferrule, the tooth should be viewed as compromised and the patient informed accordingly. It should not, however, be considered an absolute contraindication to treatment, rather an important prognostic feature to be included in the consent process (Figure 5). With minimal or absent ferrule, the clinician becomes dependent upon intraradicular aids (eg Nayyar cores and posts) to retain the coronal restoration. Crown lengthening and/or orthodontic extrusion may be considered in cases where the tooth is of strategic importance or planned as an abutment, therefore demanding improved mechanical characteristics.



Figure 4. The post crown in the UL1 was removed to allow endodontic access. It is clear that this tooth has sufficient coronal dentine to permit a ferrule effect and thus predictable restoration following re-treatment.



Figure 5. The LR4 has no coronal dentine remaining and therefore no ferrule is possible. The bonded fibre composite post must be relied on for retention and resistance form.

Posts

The primary function of a post is to retain a core in a tooth with extensive loss of coronal tooth structure.¹⁵ Posts are associated with three significant drawbacks¹⁶ (Figures 6 and 7):

1. Preparation may disturb the seal of the root canal filling, which may lead to microleakage and failure;¹⁷
2. Removal of sound tooth structure, thereby weakening the root which may result in premature loss due to root fracture;¹⁸



Figure 6. Vertical root fracture of an upper canine following restoration with a post-retained crown.

3. There is an increased risk of iatrogenic perforation.¹⁹

As such, the decision whether to use a post must be made judiciously and currently there appears to be a definite trend towards reduced post usage. Without clear guidelines from definitive research, specific factors for the individual tooth and clinical situation require careful consideration. Ultimately, the evaluation of whether a post is needed is based on how much natural tooth substance remains to retain a core build-up and support the final restoration after caries removal and endodontic treatment are completed. It is sensible to consider placement of a post only if there is such significant loss of coronal tooth tissue that a core cannot be retained. Practically, the divergent roots and pulp chamber space of molars should mean posts should not be required, but anteriorly these features are not present. Therefore, for structurally compromised anterior teeth, post-retained cores remain an essential part of restorative dentistry.

If the decision is made to place an intra-radicular post, there are several aspects to consider, including the type of post, size and shape of post, conservation of tooth structure and the creation of the post space.

Non-metal post systems

Traditionally, the principal

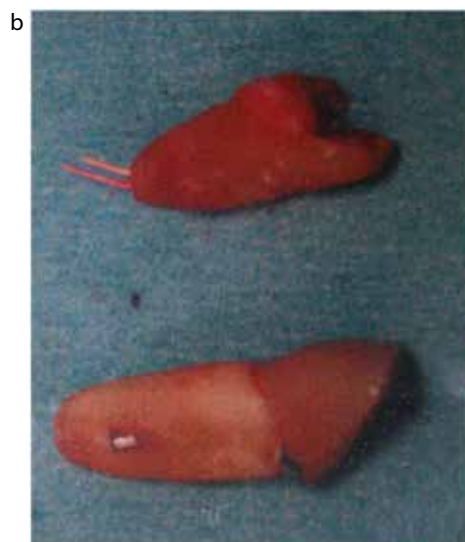


Figure 7. Following an incompetent attempt to achieve optimum length on these cast posts, the clinician has perforated apically on both UR1 and UL1. The extent of perforation UL1 is visible on the post-extraction images. (Images courtesy of Dr Niall Quigley.)

posts of choice have been direct or cast metal posts. These have several drawbacks:

- They are not tooth coloured;
- The mechanical properties of metals differs from natural tooth; and
- Failure of metal posts tends to be catastrophic root fracture.^{10,20}

Carbon, zirconia and fibre composite posts have all been introduced as alternatives to metal posts. These systems are deemed more biologically compatible with tooth tissue.¹ Furthermore, if amalgam is phased out of dentistry, clinicians must become confident with resin-based technology.

The more aesthetic glass and quartz fibre post have now replaced carbon fibre posts. Moreover, they can be bonded to dentine. Zirconium posts cannot be etched, therefore, it is not possible to bond a composite core material to the post, making core retention a problem.²¹ Retrieval of zirconium and ceramic posts is very difficult if endodontic retreatment is necessary, or if the post fractures. Some ceramic materials can be removed by grinding away the remaining post material with a bur, but this is a tedious and dangerous procedure. It is impossible to grind away a zirconium post. For these reasons, ceramic and zirconium posts should not be used.

The main advantage of using a fibre post is that the modes of failure are generally more retrievable than those of metal post systems. The use of fibre posts reduces the risk of root fracture significantly as the modulus of elasticity of these posts is closer to that of dentine.²² Fibre posts provide greater elastic support to the core of a tooth than metal posts²³ (Figure 8).

The most common causes of failure associated with fibre post systems are post de-cementation and secondary caries.²⁴ Of these, post de-cementation has been suggested as the most frequent complication.²⁵ There are many challenges to successful bonding in the root canal that may explain this mode of failure:

- Polymerization shrinkage and the unfavourable geometry for resin bonding within the root canal – a high configuration factor or C-Factor (the ratio of bonded to unbonded resin surfaces);²⁶
- Deterioration of the resin bond with time;²⁷
- Incompleteness of resin infiltration into the demineralized dentine;²⁸
- Performing the bonding steps is more difficult deep in the root canal system;
- Penetration with a curing light is limited in the root canal system, resulting in a

reliance on dual-cured materials;

- Problems posed by certain endodontic materials – both sodium hypochlorite and eugenol can interfere with bonding.²⁹

The dental literature relating to the different types of posts presents too many variables to enable a true comparison between all available post types. The profession lacks long-term clinical results, with a high level of evidence pertaining to survival data for the various post systems.³⁰ The presence of a ferrule of 1.5–2 mm sound coronal tooth structure between the core and the finish line is more important in fracture resistance than the post design or type.³¹ Nonetheless, there is a growing understanding of the benefits of resin-bonded fibre-composite post systems. Given the more predictable and less catastrophic mode of failure, we would advocate these in conjunction with composite cores wherever possible.

However, no one system has universal application. Parallel-sided or tapering pre-fabricated posts are recommended for conservatively prepared root canals in teeth with roots of circular cross-section. Excessively flared canals are most effectively managed by a traditional custom cast post. *In vitro* studies have confirmed that parallel-sided posts are more retentive than tapered posts and that threaded posts are the most retentive.³² Threaded posts which screw into dentine are not recommended as they generate residual stress in the dentine, which may result in root fracture.

Conservation of tooth structure

In creating post space, care must be used to remove only minimal tooth structure from the canal. Excessive enlargement can perforate or weaken the root, which may then split during post cementation or subsequent function. Most roots are narrower mesio-distally than facio-lingually and often have proximal concavities that cannot be seen on standard periapical radiographs. Experimentally, most root fractures originate from these concavities, because the remaining dentine thickness is

minimal.³³ Therefore, the root canal should be enlarged only enough to enable the post to fit accurately and yet passively whilst ensuring strength and retention.

Retention form

Simultaneous dislodgement of an anterior crown with its retaining post and core is a frequent occurrence and results from inadequate retention form of the prepared tooth.³⁴ Post retention is affected by the following factors.

Preparation geometry

Some canals have a near circular cross-section. These can be prepared with a twist drill or reamer to provide a cavity with parallel walls minimal taper, allowing the use of a preformed post of corresponding size and configuration. Conversely, canals with elliptical cross-sections must be prepared with a restricted amount of taper to ensure adequate retention and eliminate undesired undercuts.

Post length

If a post is shorter than the coronal height of the clinical crown of the tooth, the prognosis is considered unfavourable, because stress is distributed over a smaller surface area. As post length increases, so does retention.³² Most endodontic texts advocate maintaining a 5 mm apical seal, whilst 3 mm is considered the absolute minimum.

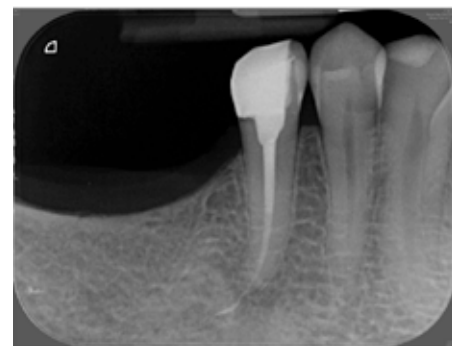


Figure 8. Greater than 50% of tooth structure was lost and there was minimal ferrule distally on the LR5. A fibre post was placed followed by a composite core.

Post diameter

Increasing the post diameter in an attempt to increase retention is not recommended because the results have minimal retention advantage and unnecessary weakening of the remaining root. Empirical evidence suggests that the overall prognosis is good when post diameter does not exceed one third of the cross-sectional root diameter.³⁵

Post surface texture

A serrated or roughened post is more retentive than a smooth post.³⁶

Luting agent

Using adhesive resin luting agents have the potential to improve performance of post and core restorations: laboratory studies have shown improved retention.³⁷

Resistance form

The resistance to lateral displacement largely stems from the

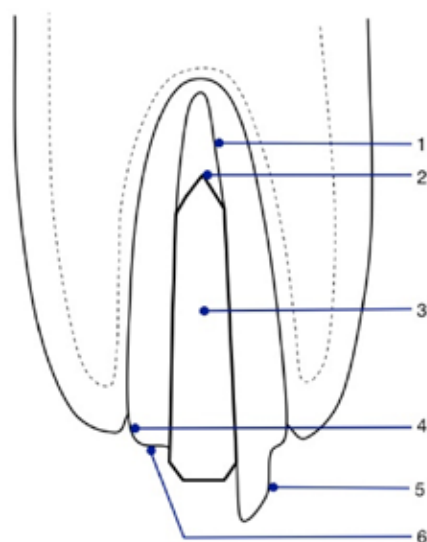


Figure 9. Six features of successful design. 1 – adequate apical seal; 2 – minimal canal enlargement (not beyond the original shaping); 3 – adequate post length (within 3–5 mm of the apex); 4 – extension of final restoration margin onto sound tooth tissue; 5 – vertical wall to prevent rotation and allow ferrule incorporation into crown; 6 – positive vertical stop (to promote axial loading).

presence of a ferrule effect.

Figure 9 demonstrates six key features of post design, placement and subsequent preparation that may all contribute to long-term success of the endodontically-treated and extensively compromised tooth.

Indirect restorations

The overwhelming majority of reports in the literature supports the need for cuspal coverage restorations of endodontically-treated posterior teeth, and a strong association between the success of endodontically-treated teeth and crowned teeth has been shown.³⁸ However, no consensus exists regarding the preferred type of final restoration for endodontically-treated teeth.³⁹ More recently, partial restorations such as indirect onlays are advocated as these

restorations preserve more sound tooth structure than does a full coverage crown, while at the same time providing cuspal coverage to protect weakened cusps⁴⁰ (Figure 10). If it is anticipated that after crown preparation the buccal and/or lingual walls will have less than 1 mm remaining dentine thickness, a partial coverage restoration should be considered.

Whatever the evidence suggests, the patient must be involved in the decision-making process. Though best practice indicates indirect restoration of many endodontically-treated teeth, many patients do not want or cannot afford this ideal. It is imperative in these circumstances that the core is placed to the best possible standard and consideration given to providing cuspal coverage with the chosen plastic

Clinical Examination

- Tooth type, alignment, drifting, over-eruption
- Length and location of edentulous span
- Existing restoration size and quality
- Periodontal support
- Clinical crown height
- Inter-occlusal clearance
- Assessment of opposing dentition or prosthesis

Occlusal Examination

- Evidence of parafunction
- Static contacts
- Dynamic contacts
- Presence of interferences (working and non-working side, RCP-ICP, protrusive)

Radiographic Examination (consider horizontal parallax views for multi-rooted teeth)

- Root length, configuration
- Quality of endodontic treatment
- Presence of periapical disease
- Crown:root ratio
- Canal curvature, preparation taper
- Periodontal bone levels

Clinical Investigation

- Removal of existing restorations and carious tissue
- Examination for the presence of cracks on the pulpal floor
- Assessment of remaining coronal tooth tissue

Table 2. Factors to consider when assessing the favourability of a tooth to act as an abutment.

restoration (Figure 11). Figures 12 and 13 demonstrate algorithms that may help clinicians decide upon optimum strategy for restoring the root-filled tooth.

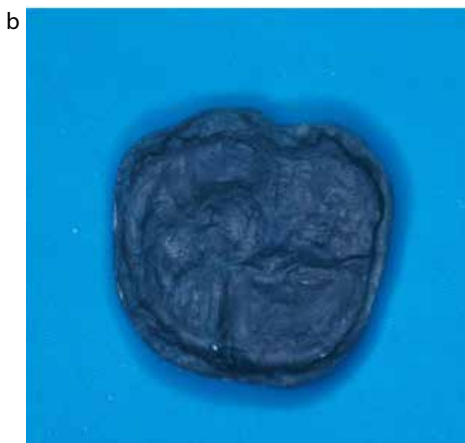


Figure 10. (a–c) Minimal preparation adhesive onlays are an excellent strategy for protecting remaining tooth structure whilst minimizing additional tooth removal. Gold can be heat-treated to form an oxide layer permitting cementation with bi-functional resins such as *Panavia*. (Images courtesy Professor Julian Satterthwaite.)

Prosthodontic interface

Abutment tooth assessment

Endodontically-treated teeth are often required as abutments for fixed and removable prostheses. With this comes a very specific set of problems that must be recognized when planning restorative treatment and getting patients to consent to the likely success of such treatment plans.

Posterior teeth are predominantly exposed to axially directed forces. When such a tooth acts as an abutment, it is now also exposed to greater non-axial forces. This is especially true if we consider cantilever bridges and the terminal abutment for a Kennedy Classification I partial denture. In such situations, extra consideration needs to be given to the amount of remaining tooth tissue, with the resistance form of

any planned restorations being particularly important. This involves careful assessment not only of clinical crown height, but also the thickness of remaining dentine. In order to do this, all existing restorations and carious tissue must be removed and the amount of tissue removal for any planned restoration also needs to be visualized. This can be particularly challenging when abutments are planned to be restored with crowns incorporating milled guide surfaces, which require extra tissue removal (Figure 14).

It is advisable to remove any remaining tooth tissue which will be less than 1 mm thick, as this will be prone to fracture. Once this has been undertaken, the clinician can now better assess the suitability of the tooth to act as an abutment and if extra retention from the root canal will be required in order to retain a restoration or core. Location and span of the prosthesis will also be important, as different forces will be exerted on anterior and posterior abutments. Anticipation of the forces which the tooth will be subjected to require assessment of any parafunctional activity and the opposing dentition. Obviously, this is only a small part of the abutment tooth assessment and the factors that need consideration are presented in Table 2.

Prosthesis design

Once careful consideration of the factors outlined in Table 2 has been undertaken, the feasibility of a fixed or removable option can be considered.

Abutments for fixed prostheses

Abutment teeth requiring a post-retained restoration should not be used as the sole abutment for a fixed prosthesis (cantilever design) as there is a significant risk of root fracture and de-cementation¹⁶ (Figure 15). When fixed-fixed designs are planned, the clinician needs to consider the different support which can be offered by the two abutments if only one is root-filled. Although tempting, utilizing double abutments can result in further problems and should be avoided. Such restorations are more difficult for patients to clean and for maintenance of periodontal health. Additionally, the forces generated during function can cause



Figure 11. (a, b) Following RCT LL6, cuspal coverage was achieved with direct composite. The clinician should aim for 1.5–2 mm thickness of composite (or amalgam) as otherwise this may necessitate additional cuspal reduction.

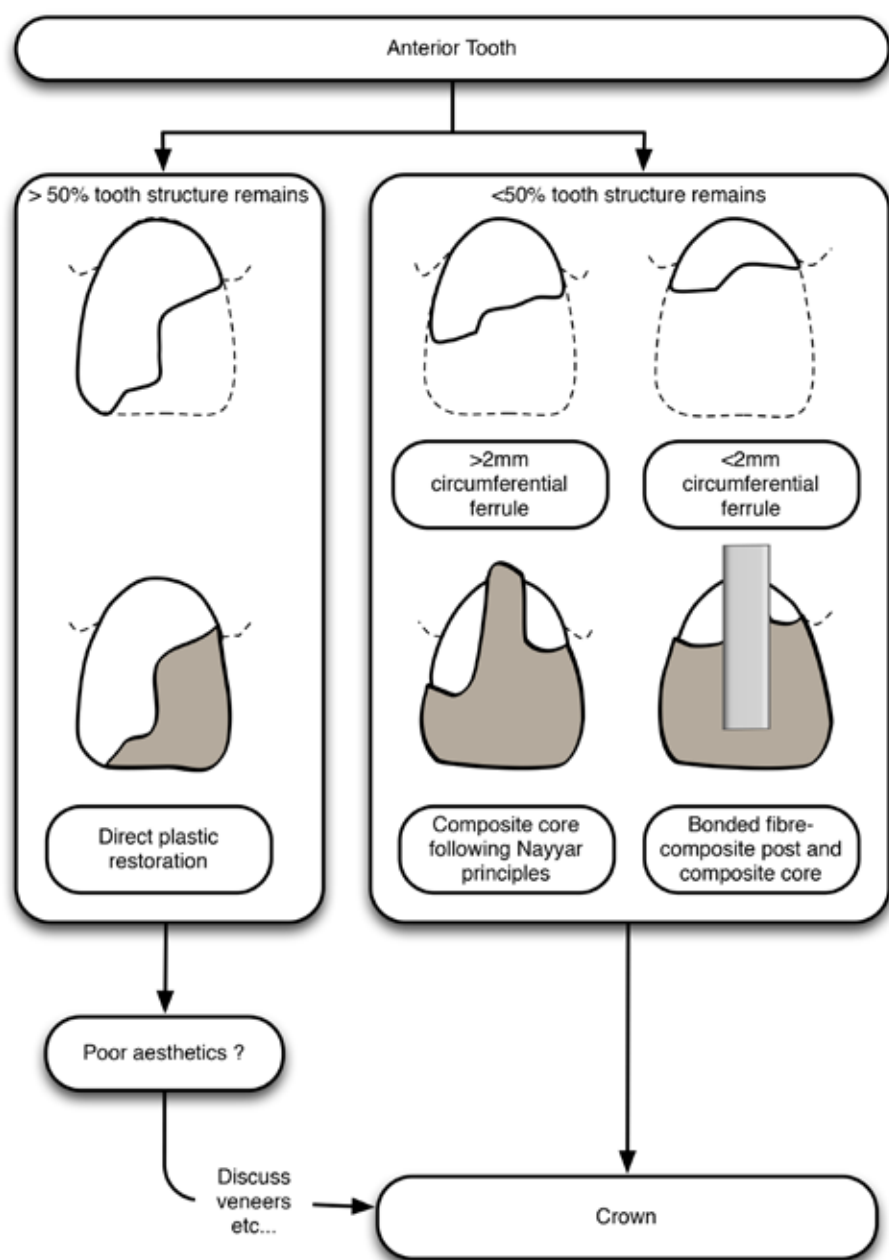


Figure 12. An algorithm to aid restorative treatment planning of anterior teeth following endodontic treatment.

- To provide simple overdenture abutments which support the prosthesis, enhance bone preservation and improve proprioception
- To allow placement of intra-coronal precision attachments to facilitate support and retention of a removable prosthesis and improve aesthetics
- To allow retention of a restoration where insufficient coronal tooth tissue remains by placing a post in the root canal
- When teeth have significantly over erupted, in order to re-establish the occlusal plane as part of a comprehensive prosthodontic rehabilitation

Table 3. Indications for elective endodontics.

the most distal retainer to de-cement, resulting in microleakage and recurrent caries.

Other options for managing such situations include the use of a fixed-moveable design (Figure 16). Fixed moveable bridges theoretically allow less transmission of force to the weaker abutment by allowing some independent movement of abutments and facilitating removal of the compromised abutment without destroying the prosthesis. Clinicians must be aware that joints only allow movement in a vertical direction, so may have limited use when lateral forces are considered. In addition, joints may require additional destruction of tooth structure and consideration should be given to the positioning of the joint.

Novel approaches to bridge design

If multiple edentulous areas are present and the remaining teeth are endodontically-treated, then provision of multiple cantilever bridges may not be a sensible option. In such circumstances, consideration can be given to the use of copings. Each tooth is prepared to receive a coping with milled surfaces. These teeth can then be used as abutments for a tooth- and tissue-supported prosthesis or one which is entirely tooth-supported. The latter can be cemented with temporary cement. This essentially creates a 'weak link' in the prosthesis, so that it is easily retrievable if problems arise.

Endodontics as an adjunct to prosthodontic treatment

In rare circumstances, endodontic treatment may be provided electively in order to facilitate prosthodontic reconstruction (Table 3). Elective devitalization of a tooth should not be undertaken lightly and a meticulous assessment of the risks and benefits must be undertaken and thoroughly discussed with the patient. The clinician must have a realistic perspective of his/her own capabilities and that the canal morphology is favourable for a positive outcome. Moreover, the clinician needs to be confident that the resultant restoration will have the best chance of success and

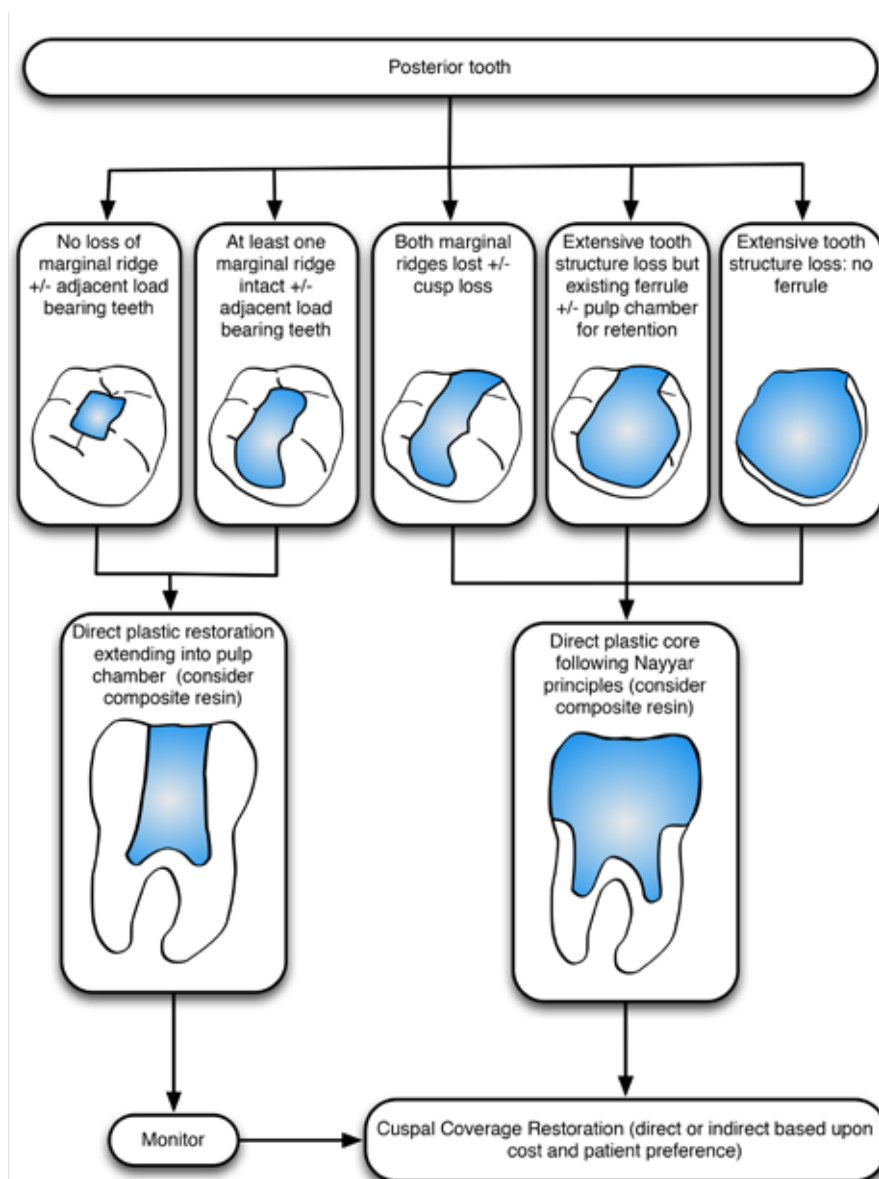


Figure 13. An algorithm to aid restorative treatment planning of posterior teeth following endodontic treatment.

this needs to be carefully planned before endodontic treatment is instigated (Table 4). Despite this, when used appropriately, it can significantly enhance the outcome of prosthodontic treatment.

Complications

The literature would suggest that the use of root-filled teeth as abutments are associated with a higher incidence of failure. Studies have reported a significantly higher failure rate of endodontically-treated teeth serving as bridge and partial denture abutments compared with those restored

with a single crown.¹⁶ In addition to this, prosthodontic treatment may also result in the need for subsequent endodontic treatment. The risk of pulpal necrosis associated with crown preparation has been reported to be significantly higher in those teeth which act as a bridge abutment.⁴¹ Such factors need to be carefully considered and articulated to patients during the consent process.

Planning for failure

If used, joints should be placed to facilitate removal of the retainer



Figure 14. Milling crowns requires more extensive palatal reduction.



Figure 15. When planning the replacement of this bridge, 'like-for-like' may be replaced, but it may be preferable to convert this to a fixed-movable design with a joint acknowledging the differential support of the abutments.



Figure 16. A joint incorporated into the pontic LL6 to allow for the differential support of the LL7 and LL5.

on the compromised abutment whilst not disturbing the rest of the prosthesis. If a partial removable prosthesis is planned, it is sensible to distribute retentive components across other teeth should the root-treated tooth fail. Furthermore, the chrome framework should be extended to the abutment to facilitate the addition of a tooth if necessary.

Conclusions

Patients are not well served if

- Peri-apical radiographs utilizing horizontal parallax for multi-rooted teeth. Assessment of canal morphology, periodontal bone levels
- The final prosthesis and restoration needs to be designed
- Assessment of remaining tooth tissue by removing existing restorations and visualizing amount of tissue removal needed for the restoration/trial preparation on a model of the unrestored tooth
- Articulated study models and wax trial/diagnostic wax-up to assess inter-occlusal clearance
- Single visit endodontic treatment to minimize the risk of canal contamination
- Careful planning of how the tooth will be temporized to minimize the risk of bacterial contamination when indirect restorations are planned

Table 4. Factors to be considered when planning elective endodontics.

the endodontic treatment is successful but the coronal restoration fails. Long-term success of endodontic treatment is highly dependent upon the restorative treatment that follows. There is not one post, core, or final restoration that can be used in all clinical situations. Clinicians must consider the functional and aesthetic endpoints for each tooth when considering the restorative protocol. Clinicians must also be aware that endodontically-treated teeth present challenges when used as abutments. An awareness of these is essential in restorative treatment planning. The restoration process is a delicate balance between preserving and sacrificing tooth structure. Whatever the clinical scenario, certain key philosophies must be remembered:

- The clinician must strive to protect tooth structure wherever possible;
- Posts are simply a means of retaining a core; if the core can be retained without posts they should not be used;
- Using bonded core materials helps minimize unwanted tooth removal. Furthermore, with the systematic phasing out of amalgam, practitioners must become proficient with resin-based alternatives.

If there is no ferrule, the prognosis becomes guarded for that tooth.

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