The restoration of endodontically treated teeth (ETT) has been guided historically by anecdotal empiricism rather than biomechanical dynamics. Decisions regarding the configuration of the restoration, the diameter of the post channel, and the post and core materials to be used have plagued foundational dentistry for decades.1, 2 The loss of coronal tooth structure due to caries,3 excessive access cavity design4, 5 and the taper of the root canal preparation are vectors that will create stress at the cervical region during functional loading.6, 7 The ongoing confusion regarding design and materials has caused paradoxical statements and illogical contradictions to be factored into the restorative matrix for ETT.

The introduction of fibre posts has altered the root to restoration harmonic. Fibre posts provide a reliable alternative to metal posts (cast or prefabricated), as their modulus of elasticity (20 GPa) is closer to that of dentine than that of metal posts (200 GPa). Stiff, hard metal posts transfer forces along their long axis, creating a wedging effect on tooth structure. This can lead to catastrophic failure. The use of fibre posts obviates such an event.8, 9 Factors in the decision-making process for the use of posts include many components (Table 1).10–24

ETT are weakened by the loss of strategic tooth architecture, resulting in structural and occlusal compromise. This is dependent on the amount of native tooth structure removed owing to previous or existing caries, the state of the current restoration and the volume of tooth structure removed during the endodontic treatment procedure. ETT are more vulnerable to loss than teeth with vital pulps owing to the possibility of either recrudescent or persistent post-treatment disease subsequent to root canal therapy.25 Historically, ETT were considered to be brittle, subject to fracture owing to the loss of tooth vitality, decreased moisture content, resultant inelasticity and the loss of collagen cross-linking. Contemporary studies comparing ETT to contralateral vital teeth challenge these findings: no decrease in compressive or tensile strength was associated with changes in the water content of dentine.26–30

In the case of ETT, the distribution of stress concentration zones and the magnitude of tensile stresses have been perceived to increase significantly when tooth structure is lost or occlusal loads are delivered off-angled to the long axis of the tooth. Fracture resistance is a function of resistance to deformation under load. Restorative materials are less likely to endure stress vectors with sustained load, further validating the need for bio-minimalism of ETT restorations.31–35 Also, the loss of tooth structure at the floor of the pulp chamber in ETT leads to significant biomechanical changes in as little as three weeks and ensuing recontamination of the pulp canal space, resulting in a higher incidence of fractures.36, 37 The more native tooth structure retained in ETT, the more enhanced the load management during function, the more effective the

Determinants

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Table 1: Factors in the decision-making process for the use of posts.

Next-level endodontic restorative continuum—a new perspective

Root to restoration

Dr Kenneth S. Serota, Canada
stress management and the more predictable the long-term prognosis.38, 39

Biologic width

Biologic width is the natural seal that develops around teeth and that protects the alveolar bone from infection and disease (Fig. 1). The dimension of biologic width is not a constant; it depends on the location of the tooth in the alveolus, and it varies from tooth to tooth and the configuration of the tooth. Biologic width is essential for the preservation of periodontal health. It is sustained by the removal of any irritation that might damage the periodontium (marginal discrepancies). Exposure of sufficient sound tooth structure in the case of a deep subgingival tooth fracture or carious lesions enhances the retention of the restoration, ensures accurate impression taking and enables correct placement of the restorative margins without violating the biologic width. This is an imperative in the aesthetic zone in patients with uneven gingival margins or excessive gingival display.40, 41

The choice of marginal position is either supragingival, equi-gingival or subgingival. Restorations placed where the alveolar bone is thin or the gingiva is thin and highly scalloped are prone to recession.42, 43 When a restoration invades the biologic width, the body’s response is to move the attachment zone apically until a tolerable biologic width is re-established.44

Ferrule

The ferrule effect is an enduring foundational tenet in restorative dentistry. It is defined as the height of natural tooth structure extending from the crown margin coronally. Numerous studies have reported that a 2 mm ferrule is required to resist displacement of the crown from the remaining tooth structure. The effectiveness of the ferrule in the restoration of ETT is determined by (1) the height and width, (2) the number of remaining walls, (3) the location of the ferrule, (4) the condition of the residual tooth structure, (5) the tooth type and (6) the degree of parafunctional loading (Fig. 2).47

Exposure of sufficient sound tooth structure in the case of deep subgingival fractures and/or carious lesions enhances the retention of the restoration and enables
correct placement of the restorative margins without violating the biologic width. This improves aesthetics in patients with uneven gingival margins and excessive gingival display. In situations where a substantial volume of tooth structure is lost, adhesive materials will not overcome the lack of ferrule and should not be an alternative to sound engineering principles when restoring ETT.

There are two ferrules; the crown ferrule and the core ferrule. The greater the height of residual tooth structure above the margin of the preparation (crown ferrule), the greater the fracture resistance. The same premise applies to the buccal thickness (core ferrule). Ideally, a 2.0mm crown ferrule and 2.4mm dentine thickness (core ferrule) minimises the fracture potential in molars. Full-coverage preparation for ETT maxillary and mandibular molars, regardless of the coronal ferrule height, results in diminished buccal thickness and increased fracture potential (Fig. 3). There are numerous contra-indications to achieving an ideal ferrule: immunological disease, close adjacent roots, tori, the ascending ramus, muscle insertions, furcation exposure and lip position. It is best to do a risk–benefit analysis by creating a provisional restoration prior to crown lengthening to ensure that the restorative treatment plan objectives can be met (Fig. 4).

The paradigm shifts

The developments in adhesive restorative technologies and techniques have enabled functional and aesthetic reconstruction of debilitated tooth structure when adequate coronal tooth structure remains. A more conservative,
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non-invasive rehabilitation is possible for rebuilding the integrity of the residual tooth structure. Improvements in direct restorations relating to the enhanced properties of composite resins have engendered a shift in the traditional default full-coverage treatment plan. In order to compensate for parafunctional occlusal forces, the marginal placement of a protective restoration should provide cuspal coverage.

In order to compensate for parafunctional occlusal forces, the marginal placement of a protective restoration should provide cuspal coverage. Posterior ETT have been reported to have greater cuspal flexure then non-ETT. Teeth missing marginal ridges allow greater cuspal flexure then teeth with intact marginal ridges, whether endodontically treated or not. Direct or indirect onlays can be used when there is residual tooth structure that is not undermined and if the marginal ridges are intact. Onlays with cuspal shoeing and full-coverage crowns restrict cuspal displacement and will prevent coronal fracture under loading (Fig. 5).

Clark advocates a substantially altered perspective on the reconstruction of ETT: (1) enamel bevels; (2) flared walls; (3) aluminium oxide-blasted; (4) and etched and uncut enamel. He advocates monolithic composites, in contrast to porcelain fused to metal, dilithium silicates and zirconia. He recommends not layering, the use of a translucent matrix system and the removal of biofilms with a slurry of pressurised air, water and mild abrasive.

**Access cavity design revision**

Recently, a trend towards patient-centric conservative endodontic cavities (CEC) has changed the focus of restoration of ETT. As the adhesion era in restorative dentistry progresses, extra-coronal restorations requiring minimal preparation are replacing full-coverage restorations, depending upon the volume of tooth structure remaining. The conservative endodontic cavity preparation concept recognises that endodontics is restoratively driven; it is an access to apex, apex to access paradigm that preserves peri-cervical dentine to diminish the potential for fracture. Traditional endodontic cavity preparation is procedure-centric and prone to structural compromise. Logically, a balance between the preservation...
of native tooth structure and dentine removal for access to the canal system is beneficial. However, a minimal access could compromise the efficacy of debridement and disinfection, as it limits access to the entirety of the root canal system. The size reduction engenders the possibility that infected tissue could remain and iatrogenic symptoms ensue (Figs. 6a–8).\textsuperscript{60}

Decision-making for restoring ETT:
- Remove the restoration(s) and carious tooth structure prior to endodontic treatment in order to evaluate the restorative matrix.
- Assess how occlusal forces affect the ETT regarding the angulation and biomechanics of the residual tooth structure. Determine the algorithm of success.

- Composite or ceramic overlays are necessary when parafunctional forces are significant. Figs. 13a & b: Composite or ceramic endodontic crowns may be used when parafunctional forces are light and greater than half of the tooth structure remains (a). Composite cores and full-coverage restorations are indicated when parafunctional forces are significant and greater than half of the tooth structure remains (b).

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with canine-protected occlusion or group function on a single tooth, a bridge abutment, an abutment for a removable partial denture or a single tooth adjacent to an implant-retained prosthesis:

- Crown lengthening considerations:
  - short clinical crowns;
  - placement of subgingival restorative margins;
  - excessive occlusal or incisal wear;
  - inadequate interocclusal space;
  - partial restorative ferrule.

- Boxes or grooves for secondary retention
- Would cementation of a crown on tooth structure be more effective than on core material?
- Choice of bonding agent, total-etch or self-etch resin cements

Conservative, non-invasive rehabilitation in the adhesion era:
- Are posts a prerequisite for all ETT?
- Is there an evidence-based data analysis that has found that fibre post systems are preferable to cast or prefabricated metal post systems?
- Are there alternative means by which to reinforce teeth?
- Are there predictable adhesive restorative protocols for ETT?

Restorative algorithms are presented in Table 2 and Figures 9a–14b.48

### Conclusion

The journey from anecdotal empiricism to scientifically validated protocols used for the restoration of ETT continues. Fundamental best practices are changing. Historically, posts/cores and the circumferential reduction of residual tooth structure were the standard technique for restoration of ETT. These aggressive procedures appeared to enhance failure possibilities. Investigations from the past and those ongoing do not provide evidentiary science that conclusively substantiates post composition, post shape, core material choice, or ferrule height and width. Improvements in dentinal adhesives and bio-smart materials appear to provide an alternative restorative paradigm with maximum preservation of tooth structure and a balance between aesthetics and structural resilience.

*Editorial note: A list of references is available from the publisher.*

### About

Dr Kenneth Serota graduated with a DDS from the University of Toronto Faculty of Dentistry in Canada in 1973 and received his Certificate in Endodontics and Master of Medical Sciences from the Harvard–Forsyth Dental Center in Boston in Massachusetts in the US. Active in online education since 1998, he is the founder of the ROOTS endodontic forum and the NEXUS interdisciplinary forum. Dr Serota is an adjunct clinical instructor in the University of Toronto postdoctoral endodontics department.