EGYPTIAN
DENTAL JOURNAL

Vol. 66, 365:378, January, 2020

Print ISSN 0070-9484 • Online ISSN 2090-2360

Fixed Prosthodontics, Dental materials, Conservative Dentistry and Endodontics

www.eda-egypt.org • Codex : 24/2001 • DOI : 10.21608/edj.2020.79112

MINIMALLY INVASIVE ENDODONTICS AND PERMANENT RESTORATIONS OF ENDODONTICALLY TREATED TEETH: LITERATURE REVIEW

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ABSTRACT

The primary goal of endodontic therapy is the long-term survival of a functional tooth through the prevention and/or treatment of apical periodontitis. However, successful endodontic outcomes depend on many factors, such as the structural integrity of the tooth after root canal preparation and the quality of the final restoration. The field of endodontics is continuously changing due to the introduction of new techniques and technological advances. Currently, minimally invasive endodontics is considered as the recommended approach during root canal therapy, with permanent restorative decisions saved for the postoperative period. Various materials and techniques have been developed and/or proposed to increase the life span of endodontically treated teeth while maintaining adequate root strength and maintaining the balance between biological, mechanical, adhesive, functional, and esthetic parameters. This critical review aims to assess the literature on recent trends in conservative endodontic treatment and adhesive dentistry for the restoration of endodontically treated teeth.

INTRODUCTION

Survival of the tooth over extended periods of time is considered as a measure of success after endodontic treatment. Such success does not depend solely on endodontic treatment but also requires well-condensed obturation after the removal of necrotic and infected tissue to prevent further microbial proliferation into the canal system.[1] Achieving an adequate coronal seal is key in preventing the ingress of microbes into the canal system.[2]

Endodontically treated teeth often fracture under functional forces. This may be attributed to the excessive loss of tooth tissue after exposure to caries, physical trauma, abrasion, and erosion. [3]

Several studies have suggested that saving the natural tooth requires excellent endodontic treatment as well as follow-up for restorative treatment. Previous reports have shown that teeth that are not permanently restored after endodontic treatment are 2–4 times weaker than teeth that are permanently restored after endodontic treatment.

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Teeth that are not permanently restored may require extraction.[4-6] After endodontic treatment, the remaining tooth structure should be preserved carefully in terms of quality and integrity to provide a solid base for restoration and to increase the structural strength of the tooth. [7-9] Current efforts to restore endodontically treated teeth aim to prevent extension by maximizing the preservation and conservation of enamel, dentin, and the dentinoenamel junction.[10] This goal is currently achieved through the use of minimally invasive dentistry with the aid of magnification and electrical handpieces. Bonding is optimized through the use of immediate dentin sealing and proper forms of isolation.[11-13]

The restoration of endodontically treated teeth is often considered to be distinct from root canal treatment. However, root canal treatment as well as restoration must be considered to plan and execute the strategy that will optimize treatment prognosis.

Because of the complexity involved, dentists restoring endodontically treated teeth must ensure that every phase of treatment is appropriate, well-executed, and timely. [14-16]

In recent years, the restorative approach to endodontically treated teeth has benefited from the availability of proven and reliable adhesive dental techniques, which have expanded the restorative options available to clinicians. Although the concept of minimally invasive dentistry for dealing with endodontically treated teeth is gaining popularity, clinicians continue to face challenges in selecting the ideal restorative material for coronal coverage. The dental community has not yet reached a consensus regarding the ability of conservative coronal coverage options such as endocrowns to effectively balance biological, mechanical, adhesive, functional, and esthetic considerations in the treatment of endodontically treated teeth.

Trends towards conservative endodontic treatment

Minimally invasive endodontics

The incidence of vertical root fracture in endodontically treated teeth may be related to the amount of dentin removed during endodontic treatment, which is considered to be a modifiable factor.[17] The concept of minimally invasive endodontics should coexist with the biological and mechanical objectives of traditional access to the cavity, such as the ability to physically penetrate, funnel, and unroof the pulp chamber.[18]

Conservative access

There has recently been a shift towards reducing the amount of tooth structure removed during endodontic treatment. Instead of traditional access design, the focus is now more tailored to a specific tooth's location and the size of the access cavity.

Several modifications have improved upon traditional access cavity designs, such as the "Ninja" outline and constructed or conservative endodontic access cavities, as recommended by Clark and Khademi.[19-21] Buchanan proposed "X-entry" access cavity design, which minimizes the removal of dental material from the critical tooth trunk.[22]

Maintaining pericervical dentin

Maintaining the structural integrity of the pericervical area of the tooth (approximately 4 mm above and below the alveolar crest) is important, especially in the treatment of molars, which require pericervical dentin for long-term survival. In molars, pericervical dentin serves as the tooth "neck", increasing fracture resistance and enhancing the ferrule.[18] The tooth soffit is a small piece of "roof" that surrounds the pulp chamber and behaves like the metal that holds together the wood panels of a barrel. The soffit must be maintained to avoid collateral damage such as lateral wall gouging.[19, 23, 24]

Technological advancement

The field of endodontics has adopted numerous advancements in technology and materials. The introduction of the microscope to endodontics in the early 1990s was followed by an increase in the availability of ever-more-flexible nickel-titanium rotary instruments.[25]

Image-guided access

Recently, image-guided access utilizing 2D projection radiography as well as 3D cone beam computed tomography (CBCT) are used to precisely design the access cavity and thus improve survival outcomes.[26] One implementation of image-guided access design is "truss" access (i.e., dual access) which is the access design of choice in a mandibular molar with minimal canal convergence and a wide platform.[26]

Dynamically guided access

Dynamic guidance was introduced in the early 2000s to facilitate the accurate placement of dental implants.[27] Dr. Charles Maupin used this approach to secure dynamically guided access during endodontic treatment.[22] Static guides may be fabricated by 3D printing based on CBTC. Furthermore, intraoral scanner data can guide clinicians during endodontic access or microsurgery.[28] Dynamically guided access provides the dentist with a significant advantage. This approach does not require the use of long burs and may be performed with high-speed handpiece burs. Dynamically guided access does not require the dentist to wait for the preparation of a 3D-printed guide and allows for changes to the treatment plan to be made in real time.[22]

In dynamically guided access, the clinician gets immediate feedback about the bur as it relates to the position of the previously planned path of access and the tooth by tracking it overhead with cameras in 3D space. The data obtained with these cameras is then transferred to the software interface.[22]

Conservative root canal instrumentation

Root canals are complex anatomic systems that may be asymmetrical or oval in cross-section, with concavities and convexities on the canal walls as they branch, dilacerate, and/or divide.[29] Traditional root canal instrumentation involves the use of a large coronal taper to enhance irrigation and disinfection and to provide a convenient from of resistance for obturation procedures.[6] However, tooth survival is influenced by the distribution, amount, strength and integrity of the remaining tooth tissue.[15] Original healthy tissue has the best biological value, and the current evolution in minimalistic approaches to access design focuses on tissue preservation, by shifting the outline configuration toward greater dentin preservation and prioritizing the endodontic-restorative interface.[30]

Minimal taper design and small apical size

Fortunately, technological advances in the instrumentation armamentarium have brought us closer to the aims of minimally invasive endodontics. We are in a new era in endodontics, with the introduction of improved disinfection systems that do not require changing the non-round canal to a round shape with aggressive canal flaring.[31; 32]

Nowadays, there is a shift in instrumentation technique, from enhanced apical instrumentation and larger apical diameters to smaller apical preparations and a continuous taper throughout the canal. A larger apical diameter is associated with minimal taper in the shape of the canal, which may weaken root structure. This type of preparation promotes resistance form, a tight apical seal, and a conservative approach to creating a shape sufficient for adequate disinfection as well as the preservation of root dentin.[33; 34; 35] Researchers have shown that bacteria can be eliminated just as easily from cavities with smaller apical size as from cavities with large apical size.[36; 37]

Using super-elastic rotary and nickel-titanium instruments rather than traditional stainless steel may facilitate the treatment of a wide range of anatomical variations, resulting in preparations that are more effectively centered, requiring less straightening.[38; 39]

Advancements in root canal irrigation

The search for techniques to enhance irrigation efficacy has continued because current cleaning and shaping methods often fail to remove all bioburden from the root canal system. Recent studies have focused more on physical means that facilitate disinfection, such as sonic, ultrasonic, photo-induced photo-acoustic streaming, and laser activation.[40; 41]

The effectiveness of tissue dissolution has been reported to increase 8-fold with use of the GentleWave System (Sonendo, Inc., Laguna Hills, CA), compared with the use of conventional irrigation systems, ultrasonic irrigation, and the EndoVac.[42] When compared with the passive ultrasonic system and conventional needle irrigation, tissue dissolution with the GentleWave system removes more calcium hydroxide, even that found in the apical third of the tooth.[43] One *in vivo* clinical study reported that use of the GentleWave System for root canal treatment achieved successful healing in 97.4% of cases within 6 months of the initial treatment. The results of histological analysis showed that the GentleWave system removed 97.2% of tissue debris in the apical and middle thirds of the mesial roots of mandibular molars, including the isthmus.[44]

Vital pulp therapy - 'Endolight'

New biologically driven treatment protocols have been developed for the treatment of cases with irreversible pulpitis. Recent clinical research on vital pulp therapy has provided new insights into pulp biology. Simon et al. and Tomson et al. found that morphological changes indicating inflammation or necrosis occurred principally in the coronal pulp, while the radicular pulp remained viable.[45; 46; 47] Research has shown that outcomes following vital pulp therapy are comparable to those seen after conventional root canal treatment.[48] Moreover, with this approach, the biological immune response can improve treatment outcomes by preventing infection of the apical area. Experts advise others to retain radicular pulp tissue and to avoid full pulpectomies. This preservation of the pulp tissue maintains the tooth's physiological and defensive functions. Less hard tissue is removed, which results in stronger teeth. [45] Vital pulp therapy simplifies treatment and decreases risk for treatment complications associated with difficult root canal anatomy, at reduced cost. Patients also report less postoperative pain, in comparison to those who underwent conventional root canal therapy.[46] To ensure successful outcomes after vital pulp therapy, proper case selection and treatment protocols should be followed.[49]

Bioceramics as sealers in endodontics

Warm condensation multiphase (guttapercha-sealer) techniques are currently common practice in the field of endodontics. However, this approach increases the risk for microleakage because of the lack of adhesion or chemical bonding between the dentin walls of the root canal and the materials used to fill it, the shrinking of guttapercha after the use of warm condensation is also an issue. The quest for endodontic sealers that adhesively and chemically bond to root canal walls therefore continues.[50]

The microspace issue associated with traditional sealers can be overcome through the use of bioceramic-based sealers. Such materials are hydrophilic and adhesive, bonding chemically to the dentin walls of the root canal. Due to their hydrophilic nature and the low contact angle, bioceramic sealers can spread easily over the dentin walls of the root canal to penetrate and fill lateral microcanals as well. Thus, the traditional approach to instrumentation in the canals with (≥06 taper) is no longer needed. Moreover, tooth tissues are preserved and the risk for root fracture is reduced.[51]

Bioceramic sealers have been shown to improve the fracture resistance of endodontically treated teeth. In particular, iRoot SP (especially in combination with bioceramic-impregnated and -coated guttapercha cones) has been shown to increase the fracture resistance of endodontically treated roots.[52] Fracture resistance was also increased when the product was used in simulated immature roots,[53] and when used in mature roots with AH Plus, EndoSequence Sealer, and/or MTA Fillapex.[54] Surface bonding to the sealer eliminates a critical pathway for the coronal leakage of microbes in the case of a defective seal during coronal restoration.[55] Endodontic grafting utilizes the osseoconductive effects of cemented hard tissue to promote physiological closure of the root canal's apical orifice.[56]

Structural changes in endodontically treated teeth

Contrary to common belief, variations in biological tissue quality after endodontic treatment have only a negligible effect on the tooth's structural strength. Rather, structural strength is affected by the amount and integrity of hard tissue. The loss of tooth tissue during cavity access and other root canal preparations has a more deleterious effect on tooth strength than dehydration or physical changes in the dentin.[57]

The fabrication of a conservative access cavity has been found to minimally affect the fracture resistance of a tooth, compared with the loss of marginal ridges. [58]

One study investigated the effects of endodontic and restorative procedures on cusp durability in healthy human teeth. The results indicated that endodontic procedures, occlusal cavity preparations, loss of one marginal ridge, and loss of both marginal ridges cavity preparations reduced tooth strength by 5%, 20% and 63%, respectively. [18]

Current opinion on the restoration of endodontically treated teeth

Torabinejad and colleagues reported that the main advantage of coronal restoration after endodontic treatment is the prevention of root apex contamination. In endodontically treated teeth that do not receive coronal restoration, bacterial products tend to contaminate the root apices within 3 weeks.[59] The clinical success of the coronal restoration of endodontically treated teeth depends on the degree of destruction present initially.[60]

Recent technological advancements in the field of dentistry have led to the development of alternative treatment options for cases involving non-vital teeth with substantial tissue loss. For example, partial indirect coronal coverage restorations and endocrowns have been introduced to replace traditional post-core restorations with full coronal coverage crowns.[61]

High-precision technological advancements, in combination with the advent of adhesive dentistry, reduce chair-side time and increase patient satisfaction with treatment outcomes. Dentists work today to minimize preparation of remaining tooth structure and to preserve radicular and pericervical dentin by eliminating the need for a post. [62,63] The monoblock effect improves the distribution of masticatory stresses by eliminating the horizontal peak loads caused by the presence of a post within the root canal. [64; 65] With contemporary techniques, occlusal forces are distributed in two directions (compression forces at the cervical butt joint and shear forces along the axial walls), thereby reducing the stresses acting directly on the pulpal floor.[66] Moreover, strict adherence to the adhesive protocol results in stronger marginal sealing, which prevents microbial penetration at the tooth-restoration interface. [67; 68]

These developments in the field of dentistry indicate that traditional principles for the restoration of endodontically treated teeth, especially those with minimal tissue loss, require revision. Attention should be focused on the benefit of the post itself rather than the type of post used,[69] because the original purpose of the post is to retain the core [70] rather than to increase the intrinsic resistance of the root[71] or the fatigue resistance of posterior teeth.[72]

Selection of restorative material

Numerous studies have compared restoration materials in terms of biomechanical behavior and performance. Today's dentists have a wide range of materials to select from, and they must thoroughly understand and consider the unique biomechanical behavior of each in order to make a well-informed decision. In selecting materials, dentists seek to maximize the longevity of the restoration as well as the endodontically treated teeth. Improvements to the computer-aided design / computer-aided manufacturing (CAD/CAM) system have allowed for highly precise marginal adaptation with reduced operating time is easily.[73; 74] In comparison to conventional fabrication techniques, contemporary restorations are manufactured economically and without errors, as laboratory and clinical manufacturing processes have been streamlined.[74; 75] Fabrication of the restoration chairside through the use of CAD/CAM obviates the need for a temporary restoration. Stronger seals on endodontically treated teeth prevent marginal leakage, which previously plagued weak interim restorations.[76; 77]

Along with the improvements in CAD/CAM, new and varied restorative materials with improved mechanical and aesthetic properties are continually being developed.[78]

Leucite-reinforced ceramics with enhanced flexibility and 400-MPa fracture resistance were developed to provide a more aesthetic outcome than that achieved with feldspathic ceramics or lithium disilicate-reinforced ceramics. The use of monolithic zirconia was introduced to prevent chipping, which was common when veneering ceramic was used for early generation zirconia ceramics. In addition to improved ceramic materials, composite-based materials with elastic moduli similar to those of dentin have been developed. Materials such as resin-ceramic and polymer-infiltrated ceramic improve the absorbance of stress.[79; 80]

The endocrown is a conservative restorative option for endodontically treated teeth in which one half of the coronal structure is missing and for teeth with short clinical crowns and/or slender or calcified root canals.[64; 72; 81] Moreover, endocrown restorations can be used to rehabilitate teeth without adequate ferrule effect and/or insufficient interocclusal space for both core and crown material.[61] This concept was first proposed in 1995 by Pissis,[82] who advocated for use of the pulp chamber as a monoblock of heat-pressed ceramic to improve macromechanical retention. In 1999, Bindl and Moramann first used the term "endocrown" to refer to an all-ceramic restoration with improved macromechanical as well as micromechanical retention from the pulp chamber and adhesive cementation to the tooth. [76; 83]

In addition to the conservation of healthy tooth tissue, endocrowns also save time by decreasing the number of clinical and laboratory steps necessary, compared with conventional crown restoration.[61] Use of a monoblock has been reported to decrease the stresses that accumulate at the interface of materials with different elastic moduli. [84; 85]

In the literature, higher fracture strength values were reported for endocrowns (674.75 N), compared to conventional crowns on fiber post-composite cores (469.90 N).[72] In another study on premolars, leucite glass-ceramic endocrown restorations showed statistically higher fracture resistance (1,446.68N) than all-ceramic crowns on fiber post-composite cores (1,163.30N). These results were attributed to the increased thickness of the ceramic materials used in endocrowns and the reduced number of interfacial surfaces with use of a monoblock rather than post-core crowns. [72; 86]

Minimally invasive preparations, which maximize tissue preservation, are now considered the gold standard for restoring endodontically treated teeth. The insertion of intraradicular posts has become the exception rather than the rule.[87]

Van Dijken et al.[88; 89] found that the high rate of success achieved with the use of dentin enamel-bonded ceramic coverage reduces the need for traditional full-coverage therapy and/or placements of a post or pin(s) and core. Other laboratory studies have shown that fracture resistance was similar in teeth restored with endocrowns and in teeth with full crowns and fiber post-composite cores.[90; 91; 92; 93; 94] One meta-analysis found that endocrowns perform similarly or better than conventional treatment with intraradicular posts, direct composite resin, and inlay/onlay restoration. The clinical success rate of endocrowns over a 36-months period varies from 94%–100%;[95] the 10-year survival rate is 98.8%.[96] Otto et al. [97] reported the survival rate of endocrowns in molars and premolars over a 12-year follow-up period as 90.5% and 75%, respectively.

The fracture strength of ceramic materials in endocrown restorations was also evaluated in other studies. The highest fracture strength was reported in the resin-ceramic group (Lava Ultimate) (1,583.28 N), whereas there was no statistically significant difference between feldspathic (Cerec blocks) (1,340.92 N) and lithium disilicate-reinforced glass-ceramic (IPS e.max CAD) (1,368.77 N).[61]

Through improved physical, mechanical and aesthetic properties, fiber-reinforced composite systems have made the transition from intracoronal restorations to crown and bridge restorations. Fiber-reinforced composite systems have elastic moduli similar to that of dentin, with decreased crack propagation and higher fracture resistance than ceramics.[98-102] However, resin composite materials appear to have increased risk for microleakage over time.[61] Resin composite materials are also weaker than lithium disilicate glass-ceramics under non-axial loading conditions.[103]

Immediate dentin sealing

The immediate dentin sealing protocol has been proposed as an effective technique for sealing the dentinal tubules during the provisionalization phase, decreasing bacterial contamination, and improving bond strength in the final restoration.[12]

Traditionally, delayed dentine sealing is performed with indirect restorations at the final cementation stage. However, delayed dentine sealing results in inferior bond strength, compared to immediate dentin sealing. With the latter technique, bonding is achieved with freshly cut dentin, which is present only at the time of tooth preparation and before impression making.[104-106]

Magne et al. [13] strongly recommend immediate dentin sealing with either total-etch or self-etch dentin-bonding agents, which they claim improves bond strength in indirect restorations. Several studies have demonstrated that immediate dentin sealing results in better long-term bonding to dentin, compared to that achieved with resin cement alone in the context of delayed dentin sealing.[13; 106; 107; 108; 109; 110; 111] One study compared mean microtensile bond strength with use of a 3-step etch-and-rinse dentin bonding agent for immediate dentin sealing, compared with delayed dentin bonding. Microtensile bond strength was 5 times higher in the immediate dentin sealing group, compared with the delayed dentin bonding group.[13]

Immediate dentin sealing also prevents collapse of the unpolymerized dentine-resin hybrid layer under the pressure created during seating of the indirect restoration.[112-114] Traditional delayed dentine bonding raises two challenges. First, during insertion of the restoration, the outwardly directed flow of dentinal fluid dilutes the bonding agent and blocks microporosities into which resin otherwise would have penetrated under an immediate dentin sealing protocol.[115] Second, the pressure of the luting resin used during restoration seating can cause demineralized dentin to collapse, with effects on adhesion.[116]

When using immediate dentin sealing with indirect restorations, delayed restoration placement and delayed exposure to occlusal loading allow the dentin bond to develop and mature without stress.[106] Magne recommends that immediate dentin sealing be performed in combination with the total-etch technique,[12] which may include use of a three-step (separate primer and resin) or two-step (self-priming resin) dentin-bonding agent. When cementing the definitive restoration, the surface sealed with unfilled adhesive resin should be cleaned gently with a soft brush and pumice only. Then the entire preparation can be etched and bonded, according to the manufacturer's recommendations.[12]

CONCLUSION

By adopting the concept of minimally invasive dentistry, practitioners can switch approaches in the contexts of endodontic treatment and the restoration of endodontically treated teeth to maximize the preservation and conservation of enamel, dentin, and the dentino-enamel junction. Maintaining the structural integrity of the pericervical area of the tooth (approximately 4 mm above and below the alveolar crest) is of the utmost importance during cavity access and instrumentation. This is particularly true for the treatment of molars.

We are in a new era in endodontics, with the introduction of improved disinfection systems that do not require changing a non-round canal to a round shape with aggressive canal flaring. Recent researches have focused more on physical means that improve disinfection, such as sonic and ultrasonic techniques, as well as laser activation. The use of bioceramic-based sealers, which are hydrophilic, adhesive, and bond chemically to root canal dentinal walls, appears to be an effective approach to overcome the microspace issue associated with the use of traditional sealers.

Recent clinical research on vital pulp therapy has led to the development of new protocols for the treatment of cases with irreversible pulpitis. By preserving the pulp tissue, physiological and defensive functions are maintained, and less hard tissue is removed, which results in a stronger tooth. [45]

There has recently been a shift towards reducing the amount of tooth structure removed during endodontic treatment. Instead of traditional access design, the location and size of the access cavity are now determined by considering the specifics of a given tooth.

Modifications to access cavity design include the "Ninja" outline, an "X-entry" design, constructed or conservative endodontic access cavities, and the implementation of image-guided access design "truss" access. Dynamically guided access (3D) appears to provide a significant advantage over traditional (2D) guided access cavity procedures.[22]

The immediate dentin sealing protocol has been proposed as an effective technique for sealing the dentinal tubules during the provisionalization phase to prevent or reduce bacterial contamination, as well as to improve bond strength in the final restoration. Ongoing studies have been designed to compare materials in terms of biomechanical behavior and performance. Today's dentists have a wide range of materials to select from, and they have to understand and consider the biomechanical behavior and properties of each to make a well-informed decision.

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