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Fracture resistance of premolars treated with endodontic therapy and repaired with various pressable and machinable ceramic overlays: literature review

Mohammed Marhab,[1] Hamdi H Hamama,[1*] Salah H Mahmoud.[1,2]
[1] *Conservative Dentistry Department, Faculty of Dentistry, Mansoura University, Mansoura, Egypt.*
[2] *Conservative Dentistry Department, Faculty of Dentistry, Horus University, New- Damietta , Egypt*

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Abstract
Endodontic treatment is a common dental procedure used for treating teeth which the pulp tissue has become irreversibly inflamed or necrotic as a result of the carious process or dental trauma. This procedure which involves mechanical and chemical preparation of root canal may affect several mechanical and physical properties of the tooth structure. The endodontic treatment can also influence the longevity of the rehabilitation of endodontically treated teeth and biomechanics during the oral function. For restoring endodontically treated teeth with ceramic materials several factor and clinical decisions should be observed. In this review, the authors were addressing the effect of the endodontic treatment procedures on canal shape and mechanical properties of a tooth, and also use of machinable and pressable ceramic overlays in root canal treated teeth.
Keywords: Endodontically treated teeth, CAD/CAM, Pressable dental ceramic, Overlay

I. Introduction

The primary function of the human dentition is the preparation and processing of food through a biomechanical process of biting and chewing. This process is based on the transfer of masticatory forces, mediated through the teeth.[1] The synergism of enamel, coronal dentin and root dentin creates an integrated organ that is capable of supporting high masticatory stresses. Root dentin is an important structure to integrate the dentition with muscle-bone support. Human root dentin has higher flexural strength and more significant inelastic deformation than coronal dentin.[2] Understanding the mechanical behavior of dentin and the detailed relations to the dentinal structure provides insight into the design strategies to recover tooth functions and helps to improve dental restoration techniques, preventing catastrophic failures.[2]

When the tooth crown is structurally compromised by caries or defective restorations, root canal treatment may be necessary to maintain tooth integrity and to provide stability for coronal rehabilitation. Endodontic treatment is mainly purposed to remove the infected tissues and microorganisms from the root canal system to control the periapical inflammatory responses and infections. Endodontic treatment is a predictable therapy with a success rate up to 97%.[3] However, it was reported that some of the failure cases of endodontically treated teeth are resulted from nonmicrobial factors as well as biological factors.[4] Dentinal collagen makes a considerable contribution to the mechanical properties of dentin. Changes in these collagen fibril cross-links may contribute to the so-called "brittleness" of endodontic treated teeth.[5, 6] Loss of pulp vitality also influence moisture content of dentin and iatrogenic factors associated with various operative procedures may contribute to the fracture of endodontically treated teeth, although most of these risks are controllable.[7]

Endodontically treated teeth are structurally compromised by caries, endodontic access, present alterations in mechanical, chemical, and physical properties.[7, 8] For restoring endodontic treated teeth the first question frequently observed is: "what material is more appropriated?" and the followed question is: "which technique, direct or indirect restoration, is better for restoring endodontic treated teeth?" and also, "Is necessary to recover cusp structure?". These questions were for long time responded based frequently in personal option. Nowadays, the evidences support that the principal aspect is to use adhesive technique for creating a unique and integrated body, involving all the materials and interfaces.[9, 10] Amalgam should severely avoid to restored endodontic treated, because this material only fill cavity but does not restore the stress/strain behavior.[1, 10]

Severally structurally compromised endodontic treated teeth often require a post to retain a coronal restoration. Compared with metal posts, fiber-reinforced resin posts are the better option for root canal treated teeth.[9] The major advantage of the fiber-reinforced posts is they have an elastic modulus that is similar to dentin, which results in a more even distribution of occlusal loads through the root.[11, 12] The stress/strain distribution in root canal treated teeth restored with fiber-reinforced resin posts depends on several factors. Teeth with extensive caries, pulp involvement and loss of structural integrity can result in pain and reduce mastication due to natural adaptation. Endodontic treatment followed by direct composite restoration was an effective method to reestablish oral biomechanical performance.[13] The performance of endodontic treated teeth is strongly related to the biomechanics events involved during all the phases of the endodontic treatment19,20 and also during the restorative procedure of these teeth.[9, 14]

All ceramic restoration

Dental ceramic is highly attractive for dentists and patients owing for their combination of excellent physical and chemical properties, such as outstanding esthetics, translucency, low thermal conductivity, adequate strength, biocompatibility, wear resistance, and chemical durability.[15, 16] Dental ceramics are defined as inorganic, non-metallic material which is specifically formulated for use when processed according to the manufacturer's instructions to form the whole or part of a dental restoration or prosthesis.[17] The same standard defines dental porcelain as predominantly glassy dental ceramic material used mainly for aesthetics in a dental restoration or prosthesis. Clearly, dental porcelain is just one type of ceramic. It is easiest to think about porcelain having a composite structure comprising a crystalline phase or phases within a glassy matrix. Other types of ceramic are mainly crystalline.[17, 18]

The new classification method for categorizing ceramic restorative materials into three families based on the existence of particular qualities in their formulation in light of these and other factors, as follows: Glass-matrix ceramics: nonmetallic inorganic ceramic materials that contain a glass phase ,Polycrystalline ceramics: nonmetallic inorganic ceramic materials that do not contain any glass phase and Resin-matrix ceramics: polymer-matrices containing predominantly inorganic refractory compounds that may include porcelains, glasses, ceramics, and glass-ceramics [19]. The glass-matrix ceramics family is further subdivided into three subgroups: naturally occurring feldspathic ceramics, synthetic ceramics, and glass infiltrated ceramics. Polycrystalline ceramics are subdivided into four subgroups: alumina, stabilized zirconia, zirconia-toughened alumina, and alumina toughened zirconia (currently in development). The third group, resin-matrix ceramics, is divided into several subgroups according to their composition. Based on the above groupings, the following is a detailed description of the proposed classification.[19]

Feldspathic Ceramics Prior to the 1960s, these were the only available ceramics for making porcelain jacket crowns. Feldspathic ceramics contain three naturally occurring minerals: feldspar (potassium and sodium aluminosilicate), kaolin (hydrated alumina silicate) and quartz (silica). Only when the porcelain powder is sintered in a porcelain furnace does some of the feldspar form leucite crystals (<5% mass) within the alumina-silicate glass matrix[19]. Feldspathic ceramic crowns were aesthetically pleasing but extremely brittle. The poor physical properties were associated not only with the low leucite concentration but also with the flaws inevitably found in a sintered material.[17]

Consequently, in the 1980s and 1990s with the introduction of CAD/CAM technology,[20] blocks of fine-grained feldspathic ceramic were manufactured (Vita MKI and II™, VITA Zahnfabrik) to provide a flaw-free material which could be machined using the Cerec™ system (Dentsply Sirona). This material has been further developed to incorporate multiple dentine shades and translucencies within the block (Cerec CPC™, Dentsply Sirona) to simulate polychromatic tooth shades better.[19]

The crystals are artificially created by controlled nucleation and crystallization. The size and distribution of the crystals are determined by the composition and processing of the base glass and the subsequent heat treatment. This process allows tailor-made materials to be produced, which exhibit homogeneous structure, good optical properties, appropriate wear characteristics, as well as optimal strength.[21, 22]

The final mechanical properties of the synthetic glass ceramics are determined by two groups of factors: intrinsic and extrinsic. Intrinsic factors are crystal size, number and geometry, the distribution pattern of the crystals homogeneity, as well as thermal expansion/contraction matching between the crystal phase and glassy matrix. Long-term performance of the material also depends on the extrinsic factors such as fabrication conditions and conditions of the oral environment.[23]

During the 1980s and early 1990s, stronger glass matrix ceramics were developed with increased concentrations (40–55% mass) of leucite.[20] Materials were formulated both for traditional sintering and as ingots to be pressed in their molten state into a refractory mold (e.g., Empress™, Ivoclar

Vivadent). Although not a particularly strong material (160 MPa flexural strength), leucite ceramics continue to be a popular choice with dentists, particularly for resin-bonded veneers. This is most likely because of its excellent aesthetics resulting from the close match in refractive index between leucite polycrystals and the surrounding glass matrix.[24]

Lithium Disilicate Empress II™ (Ivoclar Vivadent), the first dental ceramic to incorporate lithium disilicate (70% vol), was introduced in the 1990s. In terms of flexural strength, it was almost three times stronger than the leucite-containing Empress™. Empress II™ underwent a minor reformulation and was replaced in 2006 by IPS e.max™ (Ivoclar Vivadent).[23]

IPS e.max™ can be formed both by pressing and CAD/CAM. At Newcastle, we prefer to use the pressed ceramic.[25] To allow for machining, blocks of IPS e.max CAD™ (Ivoclar Vivadent) contain only 40% lithium disilicate and are coloured blue. The blueness is to ensure machined restorations are tempered at 850 °C. Tempering increases lithium disilicate content to 70% and at the same time removes the blueness to give a tooth-colored restoration. It is worth noting that restorations made using press and CAD/CAM have different microstructures and different mechanical properties.

Clearly, further studies are needed to corroborate the long-term performance. The nano-fluorapatite layering ceramic, IPS e.max Ceram (Ivoclar Vivadent), is used to create a sintered aesthetic veneer onto an IPS e.max core. Alternatively, monolithic e.max restorations can be made which may offer improvements in strength, but less opportunity for matching aesthetics of adjacent teeth. IPS e.max can be used for all types of extra-coronal restorations both anteriorly and posteriorly.[26]

In common with feldspathic and leucite ceramics, it can be etched with hydrofluoric acid allowing restorations of thin section, for example, veneers, to be bonded directly to enamel. The manufacturers consider it sufficiently strong for three-unit bridges back to the second premolars, providing there is adequate connector height. However, a meta-analysis reports relatively poor survival rate for lithium disilicate bridgework at 5 and 10 years (78.1% and 70.9%).[27]To illustrate ongoing ceramic development, a lithium disilicate reinforced with zirconia has recently been introduced for CAD/CAM production (Suprinity, VITA Zahnfabrik). This material was compared in vitro with IPS e.max CAD and showed better flexural strength but greater brittleness suggesting poorer machinability. Another manufacturer has used zirconia to reinforce lithium silicate (Celtra Duo, Dentsply), again for CAD/CAM milling. It had a similar flexural strength to IPS e.max CAD and similar amounts of edge chipping after machining.[28] However, Celtra Duo had a lower Weibull modulus indicating a possible higher probability of failure at lower levels of stress.[29]

Zirconia Zirconium (Zr) is a shiny silvery metal.[30] It is relatively soft and flexible when in a highly pure form. Its most important compound is zirconium dioxide ZrO_2, chemically an oxide and technologically a ceramic material. About 0.02% of the earth crust comprises of zirconia, with the largest deposits in Brazil and South Africa as baddeleyite (monoclinic zirconia) and high proportion in Australia and India where can be found as zircon ($ZrSiO_4$) sands.[30] Zirconia was discovered by the German chemist Martin Heinrich Klaproth in 1789.[23]

Zirconia and alumina are the principal polycrystalline compounds used to create high strength cores, although pure alumina is now used much less because zirconia is much stronger. Indeed, zirconia has a greater yield strength than many dental alloys but is not as tough.[31] Zirconia undergoes transformation toughening which is a fascinating concept quite different from dispersion strengthening used in the glass matrix dental ceramics. Cores are formed using CAD/CAM to mill the ceramic in its green state and then densely sintered. This produces a structure which in microscopic cross section looks like meticulously laid crazy paving. zirconia cores rarely fail, but the overlying ceramic veneer is prone to unexplained chipping.[32]

Transformation toughening requires a substantial proportion of tetragonal zirconia (T) in the material at room temperature making it metastable.[30] When exposed to external stress, e.g. at a crack tip, tetragonal zirconia undergoes transformation to the monoclinic phase (M). This tetragonal phase and monoclinic phase transformation are accompanied by a localized 4% increase in volume and the accompanying compressive stresses can block or close the crack tip. To obtain sufficient tetragonal phase at room temperature, the zirconia is stabilized more correctly with partially stabilized, usually with yttria, but ceria is showing great promise. The proportions of the various zirconia phases and their microstructure (at both the micro- and nanoscale) depend on the amount and type of stabilizing agent used. Most dental zirconia products have been based on yttrium tetragonal zirconia polycrystals (Y-TPC).[30]

This continued transformation is also seen in dentistry with Y-TZP but has not as yet shown itself clinically to be a problem. This may be because zirconia restorations have not been followed up for that long. However, a mean reduction in crown crush strength of more than 30% resulted from autoclaving specimens at 135 °C for 2 h which the authors claimed simulated 10 years of LTAD in vivo.[33] However, the validity of such accelerated ageing has been called into question.[34]

Unwanted tetragonal to monoclinic transformation can also result from stressing the material as may occur during airborne particle abrasion (sandblasting), particularly with larger 120 µm grit particles under high pressure.[35] By contrast LTAD is not seen in ceria-stabilized zirconia combined for extra strength and toughness with nano- and micro-sized alumina particles. Typical flexural strength and fracture toughness values are 1400 MPa and 19 MPa m1/2. We can expect to see more of these stronger materials in the future.[36, 37]

There are many different zirconia manufacturers, but it would be unwise to assume that all zirconia products perform similarly.[38] Variations in constituents, grain size, purity, CAD/CAM processing and sintering may have good or bad effects. The potential problem of airborne particle abrasion producing defects and stress transformations. One suggested remedy is to anneal the restoration afterwards by heating to 1200 ° for 2 h to heal the surface by reversing the tetragonal to monoclinic transformation. This is only partly successful as the surface defects still remain which may become future sites of crack propagation.[39]

In 2005, pressed-ceramic material called IPS e.max Press (Ivoclar Vivadent AG, Schaan, Liechtenstein) was introduced to the market. There are limited data available on IPS e.max Press (Ivoclar Vivadent AG) ceramic. This pressed ceramic is intended to expand the range of applications for IPS Empress 2 (Ivoclar Vivadent AG). While it features similar physical properties to previous materials, its translucency has been improved. The IPS e.max Press (Ivoclar Vivadent AG) system is comprised of high-stability framework material that consists of lithium-disilicate (Li2O2SiO2). It can be processed using either lost-wax hot-pressing techniques (IPS e.max Press) or computer aided designed-computeraided manufactured (CAD/CAM) milling procedures (IPS e.max CAD). The restorations can be customized by using either a layering technique based on fluorapatite glass ceramic or by using the staining technique.[40]

Currently, two techniques are used for fabrication all ceramic restoration. Anthor fabrication technique use CAD/CAM system technology introduced in dental field in 1980s.[41]The CAD/CAM technology charge coupled camera device to obtain abutment tooth to produce three-dimension 3Dimage and ceramic blocks is then milled based on digital information. Restoration and crown can fabricate in single visit.[42]

IPS e.max CAD was introduced in 2006 as a lithium disilicate glass-ceramic, specifically prepared for CAD/CAM. The material comes prepared in a blue state where it is composed primarily of lithium meta-silicate (Li2SiO3), which is easier to mill and results in lower bur wear. after the milling process is completed, the material is heat treated and glazed in one step, forming the final lithium disilicate restoration.[43]

Recently, a zirconia reinforced lithium silicate glass ceramic (Vita Suprinity; Vita Zahnfabrick, Bad Säckingen, Germany) for dental CAD/CAM applications for the fabrication of inlays, onlays, overlays, partial crowns, veneers, anterior and posterior crowns and anterior and posterior single tooth restorations on implant abutments has been introduced to the dental market. This new glass ceramic is enriched with zirconia (≈10% by weight). The zirconia particles are incorporated in order to reinforce the ceramic structure by crack interruption. It is anatomically contoured as monolithic restoration due to enhanced translucency and different shades.[44]

Zirconia blocks for the CAD/CAM technology could be used in their pre-sintered or sintered state. For better quality of the restoration, it is better if pre-sintered chalk-like blocks are used so called green stage with porosity in their microstructure (50% for IPS e.max ZirCAD), so the milling process is easier, the average milling time is reduced, and the milling tools can be used longer. After milling in the CAM system, enlarged crown and bridge substructures undergo sintering process (1350–1500°C). During the sintering, shrinking of the restorations (20–25%) occurs, causing the structure densification to more than 99%, so the final properties of the material are achieved.[45]

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