

CONTRIBUTIONS OF FIXED PROSTHODONTICS DEPT., MINIA UNIVERSITY IN DENTAL LITERATURE IN TWO DECADES. (2003-2022)

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Introduction

The Fixed Prosthodontics dept.- Minia University was established in September 1999, as the first and pioneer F.P. dept. in all Upper Egypt. Four chairmen headed the department: Prof. Fatouh Ramadan (2001-2002), Prof Omaina El Mahallawi (2002-2005), Prof. Cherif Mohsen (2005-2019, 2021-2023) and associate professor Manal Rafie (2019-2021). The postgraduate studies & researches started at 2003. During these twenty years 2003-2022, one hundred & four theses were carried out according to several successive researches plans. Ninety five of them were successfully defended & nine were approved by the department council in 2022 & were successfully defended in 2023.

Review

I. Ceramics

a. Techniques of Constructions

Several studies were carried out comparing the final ceramic restoration fabricated using different techniques. Comparing the internal and marginal fit of different types of ceramics constructed by three types of impressions (conventional , direct scanning, in-direct scanning); constructed by 2 techniques (pressing, CAD/CAM) . The study was carried out in-vivo as well as in-vitro. The most accurate restorations were that constructed from direct digitalization. The worst results were attributed to the combination of conventional impression followed by pressing technique. [1].This study was contradicted by two other studies which reported that regarding marginal gap, pressable restorations were superior than CAD/CaM ones [2-3]. All different methods produce ceramic restorations within the clinical acceptable range.[1-3]. Two types of finish line (deep chamfer , radial shoulder “120°” - 1mm in thickness) were recommended to be used in both ceramic fabrication techniques. Thermocycling affects the marginal fit of ceramic restorations fabricated using either pressable or milling techniques. As regard the types of ceramic used in milling

techniques , zirconia ceramics yielded better marginal gap as well as internal fit than Li disilicate ceramics.[1,4]. In another study, a comparison was carried out between full anatomical & framework then veneering of milled zirconia ceramics, the results showed superior vertical marginal fit for full anatomical milled zirconia restorations [5].

b. Surface Treatment

Tribochemical surface treatment of zirconia and Li disilicate ceramics result in high surface roughness, with a non-uniform pattern with distinct sharp projections dotted with pores. Air abrasion showed less surface roughness with a lesser non-uniform pattern . Whereas, the use of hydrofluoric acid etching 9% resulted in the least surface roughness with moderate irregularities with peaks and valleys [6-7]. In another study , in a trial to improve the effect of the use of hydrofluoric acid etching on the micro-shear bond strength of ceramics (zirconia, Li disilicate, polymer infiltrated), HF acid was tested with monobond etch & prime . The results showed no improvement than using HF acid & silane coupling agent [8]. As regard surface treatment of polymer infiltrated ceramics, air abrasion with 50 μ m Al₂O₃ , showed better retentivity than when using 110 μ m Al₂O₃ or HF acid [9]. Laser treatment of leucite reinforced ceramic as well as Li disilicate ceramics was tested using two types of laser CO₂ and ArFl. The results showed that shear bond strength recorded by laser surface treatment were less than that with HF etching as this last surface treatment techniques showed more roughness of the surface (small micro retentive grooves). While laser surface treatment showed little material removal related to formation of pores, melting of the most superficial ceramic layer & its solidification related to the formation of elevation over the surface. EDX analysis showed no significant changes in the main elements of ceramic crystals. At the same research, there was no difference between leucite reinforced ceramic & Li disilicate ceramics as regard vertical marginal gap, fracture resistance and hardness[10]. Laser surface treatment was studied in another research , on the retention of zirconia crowns, two powers of laser were used (400mJ – 600 mJ). The results showed that laser powers didn't improve the retention and resulted in less retention than when tribochemical surface treatment was used[11]. In another study, surface treatment of zirconia ceramics by hydrofluoric acid or air abrasion were reported to be not a reliable method for production of safe and strong bond with zirconia ceramic[12]. Self adhesive resin cement reported the higher bond strength than by etch & bond resin cement. Thermocycling decreased bond strength regardless of the type of ceramic materials or the technique of surface treatment [8].

c. Thickness

Ceramic thickness was studied as regard the final color outcome of the restoration using different types of dental ceramics adhesive cements. Three types of ceramics were used (zirconia, Li disilicate, polymer infiltrated) with 3 thicknesses (0.5,1.0,1.5 mm). Increasing the thickness led to decreasing in the clarity of the ceramic .A 0.7 mm thickness was recommended by a recent study for zirconia ceramic. Polymer infiltrated ceramic was the most affected by increasing the thickness. The shade of the resin cement also played an important role in the final color outcome as the use of translucent luting agent yield less ΔE than opaque ones. Also , thermocycling effect increases by increasing the ceramic thickness[12,13,14]. Another study draw the attention that CAD/CAM techniques results in better color than pressable technique for the same thickness, this study used the same Li disilicate ceramic either pressed or milled. Also they reported that fracture strength increased with both increasing thickness or using the milling technique [15]. Ceramic composition & thickness has an impact factor upon the degree of polymerization of dual-cured resin cement due to attenuation of light reaching cement . As Li disilicate recorded the highest degree of polymerization of dual-cured resin cement, followed by the polymer infiltrated ceramic & finally the zirconia ceramics. Decreasing the ceramic thickness yields better degree of polymerization of dual-cured resin cement. Also ceramic thickness has an effect upon microhardness of dual resin cement, increasing the ceramic thickness results in decrease of resin microhardness. It was reported that increasing the degree of polymerization is always associated with an increase in the microhardness of the resin cement. [16].

d. Stains

A recent study reported that the technique of coloring zirconia ceramics has an effect on ΔE of zirconia ceramic . ΔE of pre-shaded zirconia ceramics & liquid shaded ceramics were insignificant difference before aging, but after aging , they were significantly difference. As the liquid shaded ceramics showed to be more affected leading to increasing in ΔE . Also , the more opaquer the ceramic color, the more color difference occurs for both the pre-shaded zirconia or the liquid shaded one. Translucency of zirconia ceramics is affected by the shade and not the technique of staining nor aging. There is also an interaction between technique of coloring of ceramic and aging on the flexural strength which showed an increase after aging for the pre-shaded zirconia ceramic, while showed a decrease with the liquid shaded zirconia ceramics. This may be explained by the fact that in case of pre-shaded zirconia , toughening mechanism occurs, as the t→m phase transformation led to volumetric expansion at localized area around the superficial defects resulting in a compressive stress concentrated around these defects and consequently stopping crack

propagation. At the other side, coloring liquid used in the liquid shaded zirconia may affect flexural strength [17].

e. Finishing

Different types of finishing of ultra translucent zirconia & Li disilicate ceramics such as auto glazing, over glazing, finishing & polishing enhance the translucency of ceramics regardless its type. Li disilicate ceramics is more translucent than ultra translucent zirconia ceramic and also more resistant to translucency than ultra translucent zirconia ceramic after aging. Spectral reflectance and transmission were nearly within the same range for both ultra translucent zirconia & Li disilicate, with more translucency to the latter [18].

f. Aging

Several studies were carried out studying the effect of aging on the optical and mechanical properties of different types of ceramic either in vitro or in vivo. Several types of aging were used (thermocycling, different beverages, accelerated aging machine)[12, 19-31]. They all concluded that aging affects the properties of the ceramic materials either positively or negatively. Comparing the effect of aging on the color of Li disilicate ceramic & zirconia ceramic; the results showed that zirconia ceramic was significantly negatively affected than Li disilicate ceramic by increasing the ΔE [19-20]. These results were attributed to the fact that differences in the crystalline structure of the zirconia ceramic has inferior surface finish & that the fact that zirconia ceramic has a sensitive cementation procedure due to its passive surface, so composite resin beneath zirconia ceramic may be subjected to some sort of disturbance during aging. This result was contradicted by a recent result which reported that Li disilicate ceramic was the most affected [21]. This controversy may be due to the different in aging procedures performed . Another comparison was made between Li disilicate ceramic & zirconia ceramic upon aging regarding surface roughness[21], marginal fit[22], fracture resistance [20,22]. Li disilicate was less affected by aging than zirconia ceramic as regard surface roughness, while it was the contrary as regard marginal fit and fracture resistance. Two researches were carried out comparing the effect of aging upon the Li disilicate and the polymer infiltrated ceramic according to surface roughness and fracture toughness, results showed that polymer infiltrated ceramic was the most negatively affected[23-25]. An aging research , reported that resin nano ceramic are more susceptible to color change due to aging than polymer infiltrated ceramic[26]. A recent study carried on the effect of aging on polymer infiltrated ceramic , this study concluded that subjecting polymer infiltrated ceramic to aging with different polarity, affects its color, micro-hardness and flexural strength[27]. Also the effect of luting agent upon aging on the final outcome of the ceramic restorations was studied. Phosphoric

acid (meth.) acrylates based dual cure resin cement has lower thermal & color stability than dimethacrylate and acidic matrix dual cure resin cement [19]. Also ceramic cemented with resin cement were more color stable than that cemented with resin modified glass ionomer [24]. Total etch and bond resin was the least affected by aging and yielded the highest shear bond strength with ceramic than self etch and self adhesive cement [25]. Deep chamfer finish line was reported to be less affected by aging than radial shoulder ; also it was the case with full contour restorations when compared to veneered ones [22]. A recent study was performed studying the effect of aging on the micro shear bond strength between Li disilicate ceramic and “ preheated viscous composite resin, flowable composite and flowable resin cement . Preheated viscous composite resin showed the highest μ -SBS . All three tested materials were negatively affected by aging[28]. A recent study reported a significant negative effect due to beverages consumption and bleaching on the color stability and surface roughness of CAD/CAM ceramics[29]. The effect of different aging protocols (chemical, autoclaving, thermocycling) on the optical properties of one type of CAD/CAM ceramics (high translucent zirconia) and a reinforced CAD/CAM composite, using different thicknesses (0.3,0.5 mm) was studied. The results showed that reinforced CAD/CAM composite reported higher mean of TP and percentage spectral transmission than high translucent zirconia. Thickness had a significant difference effect on translucency parameter , translucency decreased by increasing the thickness. High color change was recorded after chemical aging followed by thermocycling then autoclaving. At the same time, thermocycling & autoclaving aging led to decrease translucency and spectral transmission, while chemical aging had a reverse effect [30].

g. Scaling

The use of piezoelectric scaler up to 7 years did not affect the microleakage of polymer reinforced ceramic luted with self adhesive cement . On the contrary , had an effect on the microleakage of high translucent zirconia ceramic luted with the same luting agent, after 5 years , and the microleakage showed a continuous increasing after 7 years [31].

h. Bleaching

High concentrated light activated bleaching agent (35% hydrogen peroxide) has no significant effect on surface roughness and wear resistance on feldspathic porcelain whether manufactured conventionally (brushing) or by CAD/CAM (milling). The later recorded higher wear resistance than the conventionally manufactured feldspathic porcelain [32]. Another study was performed on the effect of bleaching agent (Home – Office) on the color and surface roughness of hybrid resin ceramics. The authors concluded that both

bleaching agent recorded clinically imperceptible color changes. Home bleaching agent affected surface roughness of hybrid resin ceramics[33].

i. Wear

Monolithic full contour zirconia ceramics are more wear resistance than lithium disilicate ceramics. Human enamel shows a little more wear value than feldspathic porcelain and monolithic full contour zirconia ceramic when they opposed ceramic restoration. Fracture toughness of full contour zirconia is more affected as regard as its fracture toughness than lithium disilicate ceramic opposing different antagonists (enamel, feldspathic porcelain, Ni-Cr alloy, lithium disilicate ceramic , monolithic full contour zirconia ceramic [34]. Another study was carried out to assess the wear of three CAD/CAM ceramics against natural teeth in a simulating chewing machine. The authors reported that zirconia ceramics showed the best wear behavior , followed by lithium disilicate, then the polymer infiltrated ceramic which was the most affected. This latter ceramics showed an antagonist-friendly behavior than lithium disilicate ceramics, while zirconia ceramics yielded the most wear of antagonists [35]. A recent study was performed to assess age-related wear of natural teeth (adult – pediatric) against two CAD/CAM ceramic materials (polymer infiltrated ceramic and 2 types of zirconia ceramics according to age : translucent Yttria- stabilized zirconia used for adult & Yttria- stabilized zirconia used for pediatrics. The results supported the previous study [35] , as polymer infiltrated ceramic showed the best antagonist-friendly behavior. They also concluded that WearCompare software developed by Leeds University and King’s College London in 2018 is an efficient software for 3D quantification of intraoral wear[36].

II. Designs

a. Resin bonded retainers

Resin bonded retainers (RBR)were reported to have higher fracture strength than conventional full contoured FPDs. This result was supported by a stress analysis test performed using finite element. The mode of failure for RBR was mainly adhesive , and the stress analysis test , reported stress concentration on the proximo-lingual areas, near the connector & at the connector [37].

b. Inlay retained FPDs

Two studies were performed to compare between full coverage FPDs (FCFPDs) & Inlay retained FPDs (IRFPDs). They reported that although that IRFPDs gave lower fracture resistance values than FCFPDs. Still , the reported values were higher than the maximum masticatory forces except when the connector size was 3x3 mm, as they reported that

connector size has a direct relation with fracture resistance: increasing the connector size results in an increase in the fracture resistance. Also, they reported an inverse correlation between marginal gap & fracture resistance, as an increase in marginal gap was associated with a decrease in its fracture resistance and vice versa. IRFPDs reported less marginal fit than FCFPDs, but in the range of clinical acceptability. The retentive capacity of FCFPDs was superior than that of IRFPDs, noting that the connector size has no effect on retention. Milling techniques showed that they affect the marginal fit of the restorations but not their fracture resistance [38,39]. A finite element analysis study reported that fracture resistance of IRFPDs decreased nearly 10% when pontic span length increased from 7 to 9 mm & by 25% when the MOD design of IRFPDs were utilized. The study draws the attention that zirconia ceramics may be the material of choice in case of IRFPDs as they reported higher values than Li disilicate ceramics [40]. Two different types of IRFPDs were studied (Box-shape & slice shape). They reported that the box shape was better in internal & marginal adaptation as well as microleakage. Li disilicate ceramics showed the highest internal & marginal adaptation as well as microleakage and fracture resistance, while zirconia ceramics showed the highest fracture resistance, the lowest marginal adaptation. Polymer infiltrated ceramic yielded the best internal adaptation as well as the least microleakage. Thermocycling significantly affected the adaptation and microleakage [41-42]. As regard the effect of fracture resistance, the IRFPDs recorded higher values than the onlay retained FPDs, as well as higher microleakage value than onlay retained FPDs. Monolithic zirconia ceramics recorded higher fracture resistance & less microleakage than layered zirconia ceramics, irrespective to the type of restorations [43].

c. Laminates

The effect of internal relief on the fracture resistance, color and translucency of laminates was studied. The investigators used 3 internal relief space (20,60,100 μm). The results showed that increasing the internal relief space yielded higher ΔE & decreased translucency, but didn't have any effect on either fracture resistance nor mode of failure of laminates [44]. In another research, the effect of different internal relief space (30,100 μm) and different trial cement paste shades (glycerin, translucent, white opaque, A1/light yellow, A3 opaque/yellow opaque, B0.5/white). The investigators concluded that trial cement paste with different shades is very important for the prediction of the efficiency of polymerized resin cements on the final esthetic outcome of ceramic veneers. They also draw the attention that the internal relief space with the different shades of trial cement paste didn't had any effect on the translucency of ceramic veneers but caused $\Delta E > 3.7$ which is clinically unaccepted. They also reported that feldspathic ceramics were more affected using the translucent, white opaque trial cement paste shades. On the other side,

zirconia ceramics with relative opaqueness were more affected by opaque trial insertion. Lithium disilicate ceramics were the least affected by the different shades of trial cements tested [45]. Another study about the try-in cement was carried out to investigate matching between try-in and final luting resin cement using different thicknesses (0.3-0.5 mm), zirconia ceramic was used. Three types of cement shade were tested (natural, light, warm). Results showed that the interaction between variables in this study (try-in and final luting resin & different thicknesses & types of cement shade) yielded significant effect on ΔE , i.e., these variables are dependent on each other. The results showed also that a correspondence between the color of the try-in pastes & their respective resin cements was clinically accepted with 0.5 mm thickness, except for light shade. As for 0.3 mm thickness, the result was clinically unacceptable. Finally, they draw the attention that the most important factor for color prediction or modulation of the perceived color for zirconia ceramic was the laminate veneer's thicknesses [46]. Different thicknesses of ceramics (0.5, 0.8 mm) were tested for color stability using two types of resin (light, dual cured). The results showed that the thickness of laminates had an effect on its color stability, as increasing the veneer thickness yielded more color stability after aging. While there was no effect on the type of resin curing on the color stability of laminate veneers after aging [47]. Another study, reported that machinable ceramic laminate veneers produced higher marginal adaptation and improved microleakage compared to pressable ceramic veneers when both were subjected to aging [48]. The effect of incisal edge preparation of laminate veneer either feather edge or overlapped incisal edge on microleakage using two types of ceramics (polymer reinforced ceramic, super-high translucent zirconia ceramic). The researchers reported that incisal microleakage is affected by the preparation design as feather edge preparation showed better marginal sealing than overlapped incisal edge design. Thermocycling increased incisal & cervical microleakage. Finally, they concluded that polymer reinforced ceramic has better marginal sealing than super-high translucent zirconia ceramic [49].

d. Occlusal veneer

The effect of occlusal veneer thickness on fracture resistance, color, marginal discrepancy and microleakage were studied by several researches [50-53]. Four thicknesses were studied (0.3, 0.6, 1.0, 1.5 mm). One of these studies was carried in one of its parts "in-vivo" to determine the effect of ceramic materials on marginal gap as well as color shade. A follow up duration protocol was performed, patients were recalled every 3 months. The results showed that although the two tested ceramics showed marginal discrepancies in the accepted clinical range, after 9 months, polymer reinforced ceramic had better marginal fit than lithium disilicate ceramic, the latter showed better color stability. The ΔE for the two

tested ceramics after 9 months was also in the clinical accepted ΔE [50]. Four researches investigated the effect of thickness on the fracture resistance of occlusal veneer [50-53]. The results showed that increasing the occlusal veneer thickness yielded better fracture resistance , all the four tested thickness proved to withstand forces beyond that of the normal occlusal forces [51-53]. There was no difference in fracture resistance between polymer reinforced ceramic and resin nano ceramic composite[49], while there polymer reinforced ceramic recorded higher fracture resistance than lithium disilicate ceramic [51] . On the other hand, one research concluded that 0.3 mm thickness has questionable survival rate in the oral environment [50]. As regard the effect of aging, the results of two studies showed no effect of aging on the fracture resistance of polymer reinforced ceramic or lithium disilicate ceramic [50-51] . Occlusal veneer thickness did not had any effect on marginal fit [50,53], but aging had negative effect on marginal fit. As regard microleakage , results showed that no difference between different thicknesses or different materials [52].

Many modifications for for the occlusal veneer design were investigated [52-55]. The conventional occlusal veneer design requires only occlusal reduction. In 2018 , a study was carried out studying the effect of preparing occlusal veneer with a modification “ a straight 0.5 mm bevel finish line at 70° “ and comparing it with the conventional preparation , results showed no difference between the two designs as regard fracture resistance or marginal fit [52]. In 2022, another research investigated the effect of type of finish line on both fracture resistance and marginal fit , two types of finish line were studied rounded shoulder & chamfer. Results showed that both preparations designs proved to withstand normal and above average masticatory forces. Also the marginal fit of both designs was within clinically acceptable range. At the same research , results showed that Lithium disilicate ceramics have higher fracture resistance than zirconia reinforced lithium silicate [54]. Two researches were carried out to study the effect of adding a shoulder finish line (1.0 mm) and a buccal groove (1.5 mm in depth & 2.0 mm in length) on marginal adaptation, fracture resistance and microleakage. Results showed that the addition of a buccal groove increased the marginal adaptation [53]. There was a contradicted results on the effect of a shoulder finish line in conjunction with a buccal groove on fracture resistance, one study showed that it increses the fracture resistance [53], while another study reported that this modified design gave rise to lower fracture resistance than conventional occlusal veneers (occlusal reduction only) , the results also showed that both designs were in the range of normal and parafunctional occlusal forces. Also both designs showed nearly no microleakage [55].

e. Endocrown

Three studies were carried out to compare between the traditional treatment of endodontically treated teeth with post & core & crown and the quasi-newly design of endocrown[56-58]. As regard fracture resistance , two studies were in accordance with each other as they concluded that endocrown showed higher fracture resistance than post & core & crown for both posterior and anterior teeth [56-57]. But as regard retention, post & core & crown showed higher values than endocrown, while there was no difference between the 2 restorations as regard microleakage [58]. The presence of 1 mm ferrule in case of endocrown increased the fracture resistance[56]. Increasing the length of the endocrown from the entrance of the pulpal canal from 6 mm to 10 mm increased the fracture resistance [57]. As regard the material used, zirconia ceramic recorded higher fracture resistance than lithium disilicate ceramics [57], and lithium disilicate ceramics reported higher fracture resistance than polymer reinforced ceramic, yet this later showed favorable repairable mode [56]. Another study showed that the type of ceramics affects both retention & microleakage , as polymer reinforced ceramic recorded better retention values but less microleakage values as lithium disilicate [58]. As regard method of ceramics fabrication, the results showed that milling ceramics are better than pressing in sealing , as they recorded lower values in microleakage [58].

The use of zirconia ceramic endocrown restorations as a retainers in the mandibular posterior region was studied by two investigators [59,60]. Results showed that both the fracture resistance and marginal accuracy were within the clinical accepted range. As regard fracture resistance, there was no significant difference between endocrown-endocrown retained FPDs & endocrown-veneered retained FPDs. Meanwhile, endocrown-endocrown retained FPDs showed better marginal accuracy than endocrown-veneered retained FPDs [59], which was in accordance with another research [60] which showed the same results . The least marginal accuracy was reported with post-core-crown retained FPDs[60]. Results concerning retention showed that post-core-crown retained FPDs recorded the highest values followed by endocrown-veneered retained FPDs and the least retention values were recorded with the endocrown-endocrown retained FPDs [60].

An in vitro & in vivo study was performed on the use of endocrown restoration on flared anterior root canals. Results of the in-vitro study showed that microleakage was higher for endocrown than for post & core & crown. Also, results showed that aging increased microleakage. The in-vivo study showed that regarding restoration , tooth & marginal integrity , customized post showed slightly better results than anterior endocrown, while both restorations performed equally regarding gingival health and marginal discoloration [61].

f. Vonlay

The influence of two vonlay preparation designs (with & without involving functional cusp on marginal adaptation & fracture resistance) using lithium disilicate cement & self adhesive dual cure resin cement was performed. Results showed that vonlay without involving functional cusp (the most conservative design tested) , didn't affect margin adaptation & provided acceptable margin adaptation. As regard fracture resistance, preparation design affected the resulted fracture resistance values, as full coverage restoration recorded the highest values followed by vonlay preparation involving functional cusp & the least was vonlay preparation without functional cusp. Still all 3 designs fractured at a higher level than the maximum occlusal forces. Most failure pattern obtained was considered as a favorable failure (fracture of restorations without fracture of the tooth). Authors recommended the use of more conservative preparation in case of normal occlusal forces & to shift toward more coverage restorations in case of abnormal heavy occlusal forces [62].

g. Finish line

Comparing two types of finish line (deep chamfer , feather edge) using two types of ceramics (lithium disilicate, zirconia reinforced), resulted that deep chamfer gave rise to better internal adaptation than feather edge. On the contrary, there was no difference between the two tested finish line as regard margin adaptation. All the recorded values were in the clinical accepted range. In an in-vivo study, the bacterial count in case of both tested finish line , there was a significant difference between different times, as the bacterial count showed significant increase acceleration at 1 week , 1 month , while it showed significant decrease after 2 month, but it didn't reach the pre-operative count. This increase and then declination in the bacterial count was higher in the deep chamfer finish line. While at the pre-operative count, both tested finish lines showed nearly the same bacterial count. Regarding the two tested ceramics, there was no significant difference regarding marginal & internal adaptation [63].

h. Marginal elevated technique

Deep marginal elevation technique (DME) didn't improve the fracture resistance of both feldspathic or polymer reinforced ceramics, instead it reported lower values . Although it reported values within the clinical accepted range of normal occlusion, but lower than in patients with parafunctional habits. As regard marginal adaptation, there was no significant difference between feldspathic with DME technique and without . On the contrary , there was a difference in case of polymer reinforced ceramics. As regard the effect of the resin cement, results showed that total etch resin cement showed increased the fracture resistance

of feldspathic ceramics. Meanwhile, the results showed that self-adhesive resin cement recorded better marginal seal values with polymer reinforced ceramics due to its chemically interaction with the smear layer [64].

i. Cantilever

An in-vitro study as well as a finite element study, on the effect of a ceramic posterior cantilever FPDs on vertical marginal gap distance & the fracture resistance were performed. Two types of ceramics were used (veneered & full- contour zirconia). Results showed that both tested ceramics, the marginal gap distance was within the clinically accepted range. As regard fracture resistance, the authors recommended based upon the obtained results that the two tested ceramics materials can be used efficiently for restoring missing posterior teeth using fixed-fixed design. Also, they draw the attention that full- contour zirconia can be a valid option for restoring missing posterior teeth using cantilever design [65].

j. Mutilated teeth

A finite element study was carried out to investigate fracture resistance of maxillary posterior FPDs constructed on mutilated abutments. Results showed that fracture resistance of FPDs is mainly affected by the amount of remaining tooth structure rather than the adjoining abutments were endodontically treated or not. Zirconia ceramics recorded higher ability for proper reducing of the generated stresses on the different component of FPD than lithium disilicate ceramic, due to the high toughness of zirconia. Also, finite analysis showed that in case of lithium disilicate ceramic, high stresses were transmitted to the adjoining abutments, which may be catastrophic especially in posterior mutilated abutments. Molar & premolar connectors could be the first site of fracture [66].

k. Electroforming

Electroforming copings gave rise to the least vertical marginal gag (VMG), followed by cast gold copings then Ni-Cr copings before r porcelain firing cycles. Porcelain fused to electroformed crowns showed the best marginal adaptation followed by porcelain fused to gold, and finally porcelain fused to Ni-Cr. The value of the mean of the VMG of the three tested alloys lied within the range of clinical acceptance [67].

III. Endodontically treated teeth

a. Mature teeth

Surface treatment of various types of posts was studied [68-70]. Two types of surface treatments were tested for titanium post : sandblasting , silicoating; retentivity of the post was tested . Results showed that there was no statistical difference between these 2 types of

surface treatment as well as with the control group which didn't receive any surface treatment. As for etching the root canal, results showed no effect of etching on post retention with the use of resin cement + bonding agent. While, etching root canal yielded higher post retention in case of using self adhesive cement [68]. In another study, regarding the effect of surface treatment of fiber post on the microtensile bond with composite resin; 5 groups were tested : 20% H₂O₂ + silane coupling agent , 10% H₂O₂ + silane coupling agent, hydrofluoric acid + silane coupling agent , silane coupling agent only & finally no surface treatment. Three types of composite resin were used : hybrid, flowable, core material. Results showed the use of silane coupling agent alone gave rise to the higher microtensile strength irrespective to the type of core material. Followed by increasing the percent of H₂O₂, then hydrofluoric acid & finally no surface treatment. As regard the effect of core material types on the microtensile strength between post & core, results showed that composite core material gave the highest bond, followed by the flowable composite & finally the hybrid composite. The authors concluded that the use of combination of silane and application of bonding agent for post surface is preferred [69]. A push-out bond strength comparison between the effect of surface treatment on the type of post material was carried out between fiber post & pressable ceramic post . Authors concluded that glass fiber post gave higher bond strength than ceramic post. They recommended the use of silicoating then silanization in case of ceramic post, while etching post using hydrofluoric acid then silanization for glass fiber post [70]. Using chlorohexidine as irrigant for root canal space before glass fiber post cementation was studied with 2 types of resin cement : self adhesive , dual cured. This study showed that the use of 2% chlorohexidine didn't affect post retentivity . Post retention was higher in the coronal & middle third with the use of dual cured resin cement, while it was the contrary on the apical third, where self adhesive showed higher post retention. The use of dual cured resin cement showed better sealing ability than self adhesive resin cement. Authors draw the attention that there is a correlation between retentivity & sealing ability which is related to bonding strategy and adaptation of post & cement with dentine [71]. Restoring of upper central incisor using 3 types of post : glass fiber, zirconia ceramic , lithium disilicate ceramic using 2 types of luting agent : dual cure, self cure ; was studied. Results showed that as regard fracture resistance, the best combination between post & cement was the glass fiber post luted with dual resin cement, they recommended this combination in case heavy occlusal forces. As regard post retention, , lithium disilicate ceramic with dual resin cement gave rise to the highest retention. They recommended this combination in case of questionable retention [72]. The effect of ferrule & its length on the fracture resistance of endodontically restored anterior teeth was tested. Results showed that the presence of ferrule as well as increasing its length (3.0 mm) significantly increased the fracture resistance of endodontically restored anterior teeth.

There was no significant difference for the fracture resistance of endodontically restored anterior teeth, restored by either prefabricated glass fiber post & core , and either prefabricated glass fiber post followed by the construction of a composite core [73].

b. Immature teeth

Endodontically treated immature teeth using either self etch resin cement or total etch resin cement resulted in lower fracture resistance values than mature endodontically treated teeth. Results also showed that total etch resin cement recorded higher fracture strength than self etch. As regard microleakage, both types of teeth maturity didn't affect microleakage. On the other hand , thermocycling affected fracture resistance of both types of teeth maturity. The effect of occlusal forces area of loading at anterior immature endodontically treated teeth was studied both in-vitro & by the aid of finite element analysis using three types of esthetic post : prefabricated ready made glass fiber post, direct custom made lithium disilicate pressed ceramic & indirect custom made lithium disilicate pressed ceramic. Either methods of investigation showed that location of applied forces plays a very important factor in determination of the type of material used, as loading at the beginning of the cingulum resulted in higher fracture resistance, followed by loading at the junction between incisal & middle thirds . The least fracture resistance was recorded for loading at the lingual slope of the incisal edge. Finite element analysis showed that stiff post materials transfer loads to the root dentine with less displacement. Therefore rigid post materials will not endanger the root of the tooth. As regard the effect of material on the fracture resistance of immature endodontically treated teeth, both tested posts materials (glass fiber, lithium disilicate pressable ceramic) had no effect due to close modulus of elasticity of both posts materials which is also close to that of the dentine of the root of the tooth.

IV. Implants

Several researches investigated various aspects of implants starting from techniques of impression till its effect on periodontium [76-84]. A study on the effect of implant tray on the accuracy of master model in both cases of single or multiple abutments revealed that in case of labial inclination of implant abutments, the open tray impression technique yielded accurate results. On the contrary, in case of mesial inclination of implant abutments, closed tray impression technique yielded accurate results [76]. Another study on angulated implant abutment, studied its effect on fracture resistance, revealed that increasing the abutment angulation (20°) may lead to deeper fracture of the restoration[77]. Angulation 15° led to increasing fracture resistance of single crowns than in case of straight abutment [77-78] Fracture resistance showed to be implant abutment angulation dependent , and not depending upon location. All fracture resistance values obtained in case of straight or

angulated implant abutments were higher than normal occlusal forces in case of lower first molar or upper central incisor [78] . A finite element analysis study reported that increasing the crown/implant ratio may lead to increasing stresses at implant bone interface either for separated crowns or splinted. As splinting didn't decrease stresses. The most favorable stress distribution was for 1:1 or less crown/implant ratio[79]. Another research investigated the effect of resin type (self adhesive resin cement , resin reinforced GI cement) & abutment material (titanium, zirconia) on the retention of lithium disilicate ceramic crown. Implant abutment material didn't had any effect upon retention force. At the same time, self adhesive resin cement gave rise to better retention force with the two types on implant abutment materials. Authors concluded the use of resin cement along with titanium implant abutment to yield the highest retention force. They also draw the attention that the use of resin cement with zirconia implant abutment or the use of resin reinforced GI cement with titanium implant abutments considered to be an adequate combinations as regard retention force. Finally, they didn't recommend the use of resin reinforced GI cement with zirconia implant abutment [80]. The use of retrievable cement by coating two different types of implant abutment (Ti, Zr) by either one coat of eugenol or glycerin prior to applying the final resin cement (self-adhesive) to a lithium disilicate ceramic crown, didn't had a difference between the two types of either type of implant abutment nor the type of coat materials before final cementation. As regard fracture resistance, Zr implant abutments showed less values of fracture resistance than Ti [81]. An in-vivo study was carried out to study the effect of loading (immediate, delayed 2 weeks) implant supported FPDs for completely edentulous mandibular patients. Researchers inspected the cases clinically & radiographically at different duration: at the definite restoration placement, then each 3 month for a duration of 1 year . Immediate loading induced significant bone height changes at the early stages of bone healing and early follow-up periods i.e. 3,6 months. Bone density was significantly higher at early stages & early follow up periods(3-6 months) for immediate loading. For both loading protocol, there was no evidence of mobility at the time of permanent prosthesis construction. As regard, gingival index, probing depth and plaque index, there was no significant difference between the 2 tested loading protocols [82]. Another in-vivo research was conducted to study the interaction effect of different types of provisional restorations (acrylic crown, acrylic RPDs., reinforced composite FPDs.), stages of implant surgery (one stage, two stage) and different loading protocols (immediate , delayed).Evaluation was carried out for the next 12 month after definite restoration placement, each 3 month. Authors concluded that resin bonded provisional restoration showed better gingival indices values than those of the provisional crowns in the immediate loading protocol. Resin bonded provisional FPDs yielded satisfactore results regarding esthetics, speech and oral hygiene. Satisfaction is recorded for fixed provisional

restorations than the removable restorations. No differences were detected among the 3 types of provisional restorations regarding plaque index. Bone loss was higher & bone density lower in the delayed loading protocol than that in the immediate loading protocol . Finally they recommended that resin bonded provisional restoration should not be used in cases of deep bite due to limited surface area for bonding [83]. Authors reported that implant supported cantilever FPDs produced higher strains on bone than implant supported fixed-fixed FPDs, this effect may be reduced by the addition of a supplementary short implant as extra support. Short implants are a successful substitute to standard length implants especially in case of reduced bone height and in proximity to vital structures. Finally, they concluded that there is no need to increase the length of short implant as they didn't add much of an effect to reduce strain [84].

V. Laboratory procedures

a. Casts

Stone casts obtained from pouring dental stone into a none disinfected or disinfected irreversible hydrocolloid impressions , undergo dimensional changes. Disinfecting should be performed using a spray disinfecting before pouring . Spray disinfecting has less negative effect on stone cast than immersion disinfecting [85].

b. Alloys

The method of fabrication of Co-Cr alloy either cast or milled showed clinical acceptable marginal fit as well as porcelain-alloy interface shear bond strength . Milled Co-Cr alloy recorded superior marginal fit , while cast Co-Cr alloy showed superior bonding ability to veneered porcelain [86].

c. Firing

The effect of repeated firing of zirconia ceramic (zero, 3,5,7,9) as well as its shade (A1,A3,A4) affected color coordinates $L^*a^*b^*$ values. L^* value increased, i.e. rendering the ceramic lighter. While a^* & b^* values were variables. ΔE was clinically acceptable for shade A1 for various firing cycles, as well as A4 in case of 3 & 9 firing cycles. As for 5 & 7 firing cycles with A3 & A4 as well as for A3 in case of 3 & 9 firing cycles , the resulted difference in color was visually detectable. This may be attributed to the color instability of metal oxides during firing [87]. This study was in accordance with another study that showed that repeated firing cycles affects ceramic color for zirconia ceramic as well as its translucency. The effect of repeated firing differs as regard optical properties of the type of ceramic , as it is higher in zirconia ceramic. While ΔE was less for ultra translucent zirconia ceramic & translucency was less affected in case of lithium disilicate ceramic [88].

d. Printing

The 3D printing models recorded few error as the conventional models than the digital models which recorded higher discrepancies at the inter-canines width as well as the inter-molars width. All errors were within clinical acceptable level < 0.5 mm [89].

e. Scanners

A study reported that both intra-oral (3 shape , Dental wings) & extra-oral scanners (Zirkonzhan, Amann Girrbach) showed similar model accuracy with low level of discrepancies. The Dental wings intra-oral scanner recorded the greater errors , still it was within the clinical acceptable level < 0.5 mm. Results showed that discrepancies differ from teeth, direction of measurement (occlusal measurement technique yielded the most accurate measurements), smoothness and regularity of teeth surface as in case of canine [89].

VI. Clinical procedures

a. Impression

Dual arch technique showed to be more accurate in posterior bridge than the anterior & complex bridge. Also, the vertical dimension was more accurate at the posterior area than the anterior . Authors draw the attention that the working impression should be poured first to produce accurate casts. Casts must be produced under dry condition not moist condition. The method of disinfection either by immersion or spraying had no effect of the accuracy of the produced casts. Automix yielded least dimensional changes than hand mixing [90].

b. Bite registration

Both vinyl polysiloxane either CAD/CAM bite registration material or conventional bite registration materials recorded no significant differences between them as regards accurate records in case of single missing tooth as well as in case of fully dentate. For both types of bite registration materials, centric occlusion records were more accurate than eccentric records. The time factor plays an important factor in dimensional accuracy , as immediate measurement yielded the best dimensional accuracy [91].

c. Heat generation

Intermittent reduction produced less tooth temperature than continuous reduction. As regard stone grit , fine stone grit produced less tooth temperature , followed by medium grit then coarse stone grit. Reduction location either at the 1/3 incisal or the 1/3 middle or the 1/3 cervical has no effect on tooth temperature in case of continuous or intermittent reduction.

Histological assessment showed significant decrease in odontoblasts numbers as they were aspirated into the dentinal tubules mainly with coarse grit stones used in continuous pattern of reduction as there was no odontoblasts seen . Authors recommended the use of fine grit stones at intermittent reduction [92].

VII. Corrosion

a. Ceramics

Corrosion effect on some optical & mechanical properties were studied by several researchers [93-98]. Comparison between lithium disilicate, zirconia 3Y-TZP , super translucent zirconia 4Y-TZP , ultra-translucent zirconia 5Y-TZP, high translucent zirconia & zirconia reinforced lithium silicate ceramics, was carried out by several investigators [93-97]. Results showed that 4Y-TZP, 5Y-TZP & zirconia reinforced lithium silicate, high translucent zirconia ceramics were the most affected by corrosion with the highest loss of weight , followed by lithium disilicate & finally zirconia 3Y-TZP. These results showed that all tested materials were affected by corrosion in relation to its micro structure with the least affected was the opaque zirconia 3Y-TZP which showed less monoclinic phase transformation after corrosion , also increasing the zirconia percent leads to increase the corrosion resistance of the ceramic.

As regard the effect of corrosion on the ceramic color, there was a contradicted results . Some authors reported that corrosion led to unaccepted clinical color change for all types of zirconia ceramics by recording $\Delta E > 3.7$ [93]. Others reported that color change was accepted clinically [95,96]. On the other hand , all researches testing the effect of corrosion on color change of lithium disilicate reported that color change due to corrosion was still in the clinical accepted range [93,95,96].

The impact of corrosion to translucency of dental ceramics was studied. Researches reported that all tested ceramics (lithium disilicate, zirconia 3Y-TZP , super translucent zirconia 4Y-TZP , ultra-translucent zirconia 5Y-TZP) had changes in translucency after being subjected to corrosion test. These changes led to an increase of translucency ; this was also the case after mechanical aging. Lithium disilicate ceramic recorded the highest translucency, followed by super translucent zirconia 4Y-TZP , ultra-translucent zirconia 5Y-TZP and finally zirconia 3Y-TZP[94] .

As regard the effect of corrosion on the surface roughness of dental ceramics, results showed that surface roughness decreased after corrosion [94,96]. Also, this was the case after mechanical aging [94]. Lithium disilicate ceramics showed the highest surface roughness followed by all types of translucent zirconia ceramics ; while opaque zirconia recorded the least surface roughness [94,96]. One study claimed that surface roughness

values of dental ceramics after corrosion were not within the clinical acceptable range i.e. > 0.28 μm [96].

Fracture resistance was reported to be not affected by corrosion for lithium disilicate , opaque zirconia, monolithic zirconia, super translucent zirconia 4Y-TZP , ultra-translucent zirconia 5Y-TZP & zirconia reinforced lithium silicate [93,95,97]. Except that one study [93] showed that fracture resistance of opaque zirconia increased after corrosion test. Fracture resistance was reported to be higher for opaque zirconia, followed by monolithic zirconia, than high translucent zirconia & super translucent zirconia 4Y-TZP , ultra-translucent zirconia 5Y-TZP, finally the lithium disilicate recorded the least fracture resistance values [93,95,97].

The chemical durability of hydrothermal ceramics was investigated in different pH values ranging from 1.70 to 11.72 with different protocol of firing , cooling & humidity. Results showed that corrosion rate of hydrothermal ceramic depends on pH , it is minimum at pH4 than increase in the following sequence pH2.40, pH9.18, pH1.70,pH11.72. Also, firing procedure has a pronounced effect on corrosion rate of hydrothermal ceramics as well as its porosity. Increase heating gave rise to the highest corrosion rate followed by the manufacture firing procedure following by controlled heated (slow heating & slow cooling). Authors reported that soaking hydrothermal ceramics with silane or the presence of fluoride ions in the corrosive solution leads to decrease in the corrosion rate [98].

b. Alloys

Higher corrosion rate of heated treated Ni-Cr alloy in aerated NaCl solution is compared to that of the as received alloy. Both showed difference in particle size and distribution of Cr_2O_3 on the alloy surface. Bleaching & prophylactic treatments (mouth wash , toothpaste) of heated alloy increased the corrosion resistance of the alloy in aerated 1% NaCl solution. The most pronounced decrease in corrosion rate was that of the as received alloy treated with prophylactic agent which also stabilized its passive state and resisted localized corrosion. Potentiodynamic polarization tests as well as SEM micrographs after polarization test revealed pitting attack for heated alloy treated with bleaching & prophylactic treatments and for the as received treated with bleaching agent. Resistance to localized corrosion was affected by both bleaching & prophylactic agents. Two types of corrosion tests (open circuit immersion , potentiodynamic polarization) reported mainly close measurements. [99].

VIII. Nanotechnology

The incorporation of silver nanoparticles in different dental materials was studied by several investigators [100-102]. Studying the effect of adding of silver nanoparticles or silver hydroxyl apatite nanoparticles to the feldspathic ceramic powder on bacterial adhesion, color & fracture resistance revealed the ability of the added nanoparticles led to inhibition of bacterial growth via inhibition of colonies forming unit (CFU) count. The antibacterial effect of both tested materials were more pronounced on gram-ve than gram +ve bacteria. As regard fracture strength, addition of silver nanoparticles have increased the fracture strength of dental ceramic, while the addition of silver hydroxyapatite nanoparticles have led to a decrease in the fracture strength of dental ceramic. Results also showed that addition of these to nano materials led to affect the color of dental ceramic adversely [100]. Incorporation of silver nanoparticles to provisional restorative materials led to an antimicrobial impact toward gram -ve & gram +ve bacteria. Results showed also an increase of flexure strength of provisional restorative materials [101]. Silver nanoparticles modified resin cement led to inhibition of bacterial growth via inhibition of colonies forming units (CFU) count, having a pronounced effect toward gram -ve & gram +ve bacteria. At the same time, addition of silver nanoparticles to resin cement don't affect shear bond strength with feldspathic porcelain [102]. Incorporation of silica nanoparticles into feldspathic veneering material for zirconia core resulted into improving of its flexural strength, shear bond strength to the zirconia substrate. At the same time, it had no effect on the color of the veneering porcelain. Finally, results showed that addition of silica nanoparticles to the porcelain veneering material improves its flexural strength & shear bond strength significantly after thermos-cycling without significant color change [103]. Coating zirconia ceramic Y-TZP by the dipping technique with sol-gel silica nanoparticles improved the resin bond compatibility of zirconia ceramic that clue to decrease of microleakage. Sol-gel processed silica nanoparticles showed color change of zirconia ceramics which was below the clinically detectable color change limit. Aging increased microleakage as well as color change for both zirconia crowns & silica coated silica nanoparticles [104].

Conclusions

During the last twenty years, the Fixed Prosthodontics dept. – Minia University has contributed successfully in the dental literature.

Recommendations

The author hopes that after another decade, a new review will be presented for the contribution of the Fixed Prosthodontics dept. – Minia University in dental literature.

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