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Porcelain fracture of metal-ceramic tooth-supported and implant-supported restorations: A review

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ABSTRACT

Metal-ceramic restorations are widely used in dentistry with a high degree of general success. However, fracture of these restorations does occur and usually frustrates both the dentist and the patient. Objective: This literature review discusses the factors that may lead to the fracture of these restorations whether they are tooth-supported or implant-supported with the aim of making dentists and technicians aware of these factors to avoid them. Factors reviewed include: technical factors, dentist-related factors, inherent material properties, direction, magnitude and frequency of applied loads, environmental factors, screw-retained implant-supported restorations, and posterior cantilevered prostheses. Material and Methods: A net-based search in "Pubmed" was performed and combined with a manual search. The search was limited to articles written in English. Conclusions: the published literature revealed that the factors predisposing to fracture of metal-ceramic restorations may be related to the technician, dentist, patient, environment, design of the restoration, or to inherent structure of ceramics and others. However, if the dentist and technician understand these factors and respect the physical characteristics of the materials, most of those are avoidable.

Keywords: Metal-Ceramic; Fracture; Implant-Supported Restoration; Screw-Retained

1. INTRODUCTION

Although most of the concentration today is on all-ceramic restorations, metal-ceramic restorations, whether they are tooth-supported or implant-supported, are still considered as the gold standard because of their excellent biocompatibility, consistent esthetics, superior strength, and marginal adaptation. Also, metal-ceramic restorations are durable and long-lasting [1]; however, several investigators [2-5] demonstrated that the fracture of ceramic veneers is not an uncommon problem in clinical practice and may cause the premature failure of fixed partial dentures. Bragger *et al*. [6] found that there is an interrelation between porcelain fracture and the long-term survival of the fixed partial denture. The event of porcelain fracture increased the risk for the suprastructure to become a failure at 10 years compared to a suprastructure with no porcelain fracture [6].

Numerous studies [4,5,7] have reported on the outcome of MC restorations supported by natural teeth abutments.

In a survey of crown and fixed partial denture failures, Walton *et al*. [5] found that the incidence of porcelain fracture was the second most common cause of MC fixed partial denture replacement, accounting for 72 (16%) of 451 failed restorations. Also, they found that porcelain fracture was the most common cause of failure with single crown restorations. This is in agreement with another 7-year follow-up study from Strub *et al*. [4] who found that porcelain fracture was the most common cause of MC prosthesis failure.

A systematic review [7] of 8 papers and 1,192 prostheses supported by natural teeth abutments showed that veneer fracture was a common complication of metal-ceramic prostheses, with a mean incidence of up to 3% reported for single crowns and FPDs.

Regarding implant-supported MC restorations, it has been shown that porcelain fracture is also a common complication in implant-supported restorations [8].

A follow-up study [3] of 92 cement-retained metal-ceramic implant-supported prostheses, including single-tooth restorations, showed that the porcelain fracture cumulative failure rate was 2.34%.

In another retrospective study, Ekfeldt *et al* [9] reported that 1 out of 39 cement-retained MC implant-supported restorations failed due to porcelain fracture.

Although different repair techniques are currently available, these techniques are still costly and time consuming. Therefore, the clinicians should be aware of the reasons that cause fracture of these restorations to avoid them.

The purpose of this article was to discuss the factors that lead to the fracture of metal-ceramic restorations whether they are tooth-supported or implant-supported, under the following headings: technical factors, dentist-related factors, inherent material properties, direction, magnitude and frequency of applied loads, environmental factors, screw-retained implant-supported restorations, and posterior cantilevered prostheses.

2. TECHNICAL FACTORS

2.1. Surface Treatment and Design of the Metal Coping

Warpeha and Goodkind [10] found that the fracture strength of porcelain was severely reduced when porcelain was fused to an un-oxidized metal surface and when an improper thickness of the coating agent was applied. Anthony and associates [11] indicated that when the alloy surface was depleted of oxide, a thirty percent (30%) reduction in the bond strength was noted. However, thicker oxides have been shown to increase the risk of metal-porcelain bonding failure [12].

There is controversy concerning whether bond strength is affected by increasing the roughness of the metal surface. Kelly and colleagues [13] stated that very rough surfaces may increase stress concentration at the bond. Nonetheless, Shell and Nielsen [14] believe that the metal-ceramic bond is two-thirds chemical and one-third van der Wall's force. Hence, the effect of surface roughness on bond strength is minimal as the authors minimize the importance of mechanical bonding. A finely roughened surface, however, may be wetted more easily, thereby possibly increasing the bond strength [10].

It has been shown that a design with a definite acuteness in the metal substructure has a lower ultimate fracture strength [10].

In addition, the cross-sectional dimensions and contours of connectors have a significant effect on framework strength and stability [15]. The connector must be thick enough to provide adequate resistance to occlusal loads; however, occlusal and gingival embrasures must be formed such as to ensure esthetics of restoration [16,17]. Furthermore, the occluso-gingival thickness of the pontic has an effect on deflection of framework. Bending or deflection varies directly with the cube of the occluso-gingival thickness or the pontic, making the pontic one half as thick will also make it bend eight times as much [16,18].

2.2. Compatibility between the Coefficient of Thermal Expansion of the Metal and Porcelain

It has been reported that stress concentration at the metal-porcelain interface is due to the disparity between the coefficient of thermal expansion of the metal and porcelain. [19]

A slightly lower coefficient of thermal expansion of porcelain compared with metal is considered beneficial. Such a relationship places the porcelain under compression after firing [20]. Generally, a 0.5×10^{-6}°C difference in the coefficients is desirable [21].

2.3. Ceramic Build-Up and Firing Technique

Evans *et al*. [22] highly recommended minimizing air entrapment between the ceramic particles because porosity does occur during ceramic application and can account for eventual ceramic fracture.

Cracks within ceramics may form due to incomplete densification which leaves behind angular pores. Flaws (cracks) also form in the surface of ceramics through abrasion (by dust); such cracks, coupled with low fracture toughness, impair the strength of ceramics [23].

The rate of cooling and heating during porcelain firing may also affect the stress concentration at the metal-ceramic interface [24].

Repeated firings or excessively high oven temperatures have been regarded as causes of superficial and deep imperfections or porcelain blistering [25].

2.4. Thickness of Porcelain

It has been stated that "the thicker the porcelain the weaker the restoration." The reasons behind this statement are: (1) the direct relationship between the thickness of the porcelain and the stress concentration at the metal-porcelain interface; and (2) the inherent weakness of the porcelain under tension [19]. The porcelain adjacent to the interface is generally under compression because the metal contracts more than the porcelain; however, the further the surface of the porcelain is from the interface, the greater the tension [14]. Therefore, in order to minimize the formation of microcracks, a fairly uniform thickness of porcelain is recommended [2].

2.5. Thickness and Elastic Modulus of the Metal Substructure

It has been demonstrated that the support of the veneering porcelain is directly related to the modulus of elasticity, not to the strength of the substructure material [26]. Alloys with an elevated elastic modulus resist deformation better [27]. Also, a frequent reason for porcelain fracture is the lack of rigidity and the distortion of the metal substructure [25].

2.6. Location of Porcelain-Metal Finish Lines

When partial porcelain coverage is decided upon, the position of the lingual or occlusal finish lines is important. The junction of porcelain and metal should not be located at centric occlusion contacts in order not to expose the porcelain-metal bonding to extra load. The porcelain-metal occlusal junction should also have a 90-degree or a greater angle to avoid thin "lips" of metal that may distort during function [25].

3. DENTIST-RELATED FACTORS

3.1. Anterio-Posterior Length of Pontic Span

Long anterio-posterior metal substructures flex under heavy or complex loads leading to porcelain fracture [28]. A fixed partial denture with two-tooth pontic span will bend eight times as much as a single-tooth pontic fixed partial denture will, if everything else remains unchanged [16,18]. Replacing three posterior teeth with a fixed partial denture rarely has a favorable prognosis, especially in the mandibular arch. Under such circumstances, it is better to go for implant-supported prosthesis or removable partial denture [29].

3.2. Adequacy and Design of Tooth Preparation

Inadequate tooth preparation, which results in too little inter-occlusal space for the metal substructure and the overlying porcelain, is also a reason for porcelain fracture [2]. Further, acute line-angled preparations encourage the formation of microcracks within porcelain during firing procedures [30].

3.3. Incorrect Registration of Occlusion and Articulation often Causes Destructive Premature Contacts

As a result, poor diagnosis and an improper design are important factors affecting the long-term success of fixed partial dentures, and the clinical skill of the dentist is extremely important for increasing the longevity of metal-ceramic restorations.

4. INHERENT MATERIAL PROPERTIES

Ban and Anusavice [31] indicated that the mechanical fatigue of ceramics is probably controlled by several factors including microstructure, crack length and fracture toughness. It has been shown that amorphous materials like glasses or glassy materials do not have an ordered crystalline structure as do metals, and dislocations of crystalline lattice do not exist in glassy materials; thus, they have no mechanism for yielding without fracture.

5. DIRECTION, MAGNITUDE AND FREQUENCY OF APPLIED LOADS

Llobell *et al*. [32] stated that mastication, parafunction and intraoral occlusal forces create repetitive dynamic loading; they considered impact load and fatigue load as reasons for intraoral ceramic fracture. Anusavice and Zhang [33] also reported that high biting forces could cause glass-containing dental restorations to break down.

Stress direction is another contributory factor for failure, as sometimes failure occurs at sites of relatively low local stress just because there is a large flaw oriented in the stress field and this is ideal for causing fracture [2]. White and Li [34] stated that the possible sites from which failure may start are highly unpredictable since this depends on flaw size and is related to the stress distribution. These observations support the need for protective splints for MC suprastructures to prevent fracture due to bruxism or parafunctional habits [35].

6. ENVIRONMENTAL FACTORS

Since 1958, it has been found that water can act chemically at crack tips, decreasing the strength of glasses and ceramics. This phenomenon is termed "chemically assisted crack growth" or "static fatigue" [36].

It has been demonstrated that silicate bonds in the glassy ceramic matrix are susceptible to hydrolysis by environmental moisture in the presence of mechanical stress. Reductions of 20% to 30% in metal-ceramic bond strength were found in moist environments [37]. As a result, this static fatigue leads to the propagation of fractures along the microcracks causing failure in the restoration [2].

Additionally, Anusavice and Zhang [33] showed that common beverages with low pH ranges could also cause fractures in glass-containing dental restorations.

7. IMPLANT-SUPPORTED RESTORATIONS

It has been demonstrated that implant-supported prostheses are more susceptible to fracture than prostheses supported by natural teeth since it was found that more porcelain fractures occur in implant-supported restorations compared with restorations supported by natural abutments [38]. Also, implant supported metal ceramic fixed partial dentures were found to have significantly higher risk of porcelain fracture in patients with bruxism habits when a protective occlusal device was not used, [39] and when the restoration opposed another implant supported metal ceramic restorations [40].

This is because the natural teeth and their periodontal ligaments provide proprioception and early detection of occlusal loads and interferences, while the implants lack this proprioceptive mechanism [41-43]. In addition to loss of shock absorbing feature in the ankylosed implant bone interface, both sensitivity and mobility of natural teeth cannot be duplicated in endosseous implants [44-46].

Therefore this different behavior to masticatory forces may lead to excessive load on the restoration especially if the prosthesis is supported by an implant at one end and a tooth at the other end. Complications of the suprastructure such as fracture of veneering porcelain, and others were observed in 5% - 90% of cases of tooth-implant connection [47]. However, it was demonstrated that the use of non-rigid connector decreases the forces on the suprastructure [47].

Screw-Retained Implant-Supported Restorations

Since retrievability is an important factor for implant-supported restorations to allow for their easy and safe removal; therefore, the prosthodontic components can be adjusted, the screws can be refastened, and the fractured components can be repaired [48], screw-retained restorations are preferred by some clinicians and are recommended in some clinical situations [49].

However, it has been shown that the presence of screw-access opening in the occlusal surface of the restorations significantly decreased porcelain fracture strength [49-56].

This is because the centric contact of the screw-access hole, which is usually developed with the head of the screw or with composite restorative material, may occupy 50% to 66% of the intercuspal occlusal table [57]. Hence, a minimal width of porcelain remains around the screw-access opening and thus, becomes more susceptible to fracture [53]. In addition, it has been shown that the screw-access hole of the screw-retained restoration disrupts the structural continuity of porcelain, thereby modifying the position of the center of mass of the ceramic bulk toward which the ceramic shrinks during the sintering process. This will affect the behavior of porcelain in these restorations compared with their cemented counterparts [58].

8. POSTERIOR CANTILEVERED PROSTHESES

Relatively few studies have been published on the long term efficacy of cantilever bridge work supported by natural teeth. Randow *et al.* [59] reported a higher frequency of failure with cantilevered units than bounded units; the same was stated by Strub *et al.* [60] who found out that the technical failure rate for cantilever bridges was 12.7% in patients with low-grade periodontitis.

Similarly, posterior cantilevered prostheses supported by a relatively small number of implants, seem to be particularly susceptible to fracture[61]. Technical complications (including porcelain fracture) were found to be more frequent for cantilever implant-supported prosthesis than for end implant abutment-supported one [62-64].

Therefore, to increase the success rate of cantilever fixed partial dentures, the leverage effect must be minimized by decreasing the pontic size to as small as possible representing a premolar [15,61]. Also, the pontic should possess maximum occluso-gingival height to ensure rigidity [15]. In addition, considering the different biomechanical demands for cantilever fixed partial dentures, various occlusal schemes have been advocated; such as freedom in the retrusion/protrusion range on cantilever, anterior guided lateral movements, and the absence of non-working side contacts on the cantilever [65]. Also, optimal retention from abutments were also recommended [65].

However, in implant-supported cantilever fixed partial dentures, further precautions must be taken into consideration. Clinical experiences suggest that the distal cantilever should not extend more than 2.5 times the anterior posterior spread of the implants under ideal conditions (e.g. no parafunction, no bruxism) [66]. Several biomechanical studies using an analytical mathematical models [67] and finite element analysis [68] demonstrated that a spread out arrangement of implants in the arch is more significant than the number of implants per se for the distribution of masticatory forces especially if these implants will support cantilever prosthesis. In addition to this, the inclination of distal implants reduces the axial force and bending moments independently from the number of abutments when cantilever is needed. This inclination allows simultaneous reduction of the cantilever length at the connection abutment-framework and increases the prosthesis support area [69]. Bevilacqua *et al*. stated that tilted distal implants with consequent reduction of the posterior cantilevers resulted in decreased stress values for the metal frameworks by 11.5% for 15-degree configuration, 31.3% for 30-degree configuretion, and 85.6% for the 45-degree configuration [70].

Figures 1 and **2** summarize all of the factors affecting the fracture resistance of metal-ceramic restorations in marco-level and micro-level.

9. CONCLUSION

The published literature revealed that many different factors may cause fracture of metal-ceramic tooth-supported and implant-supported restorations. These factors may be related to the technician, dentist, environment, design of the restoration, or to inherent structure of ce-

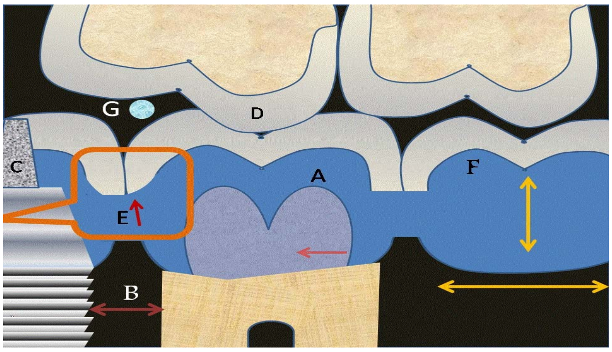

Figure 1. Macro-level variables affecting fracture resistance of metal-ceramic restorations. These include: Tooth preparations *A* (adequate tooth preparation, sufficient inter-occlusal space, rounded line-angles of preparations); Support type *B* (Tooth vs. implant); Surface integrity of crown *C* (screw vs. cement-retained); Occlusion factors *D* (avoidance of premature contacts, design cusps to guide occlusal forces in favorable directions, avoidance of parafunctions and bruxism/clenching habits); Connector variables *E* (the cross-sectional shape, dimensions, contours of connections within framework); Pontic variables (the occluso-gingival height, occlusal table area, length of pontic span); Partial coverage variables (location of porcelain-metal finish lines away from occlusal loads); Cantilever variables *F* (posterior length of cantilever in relation to support span, occlusal engagement vs freedom of movement, direction of forces on cantilever area, width of occlusal table area of cantilevered section, occluso-gingival height); Diet variables *G* (beverages with low pH ranges, biting hard food or structures accidently or habitually).

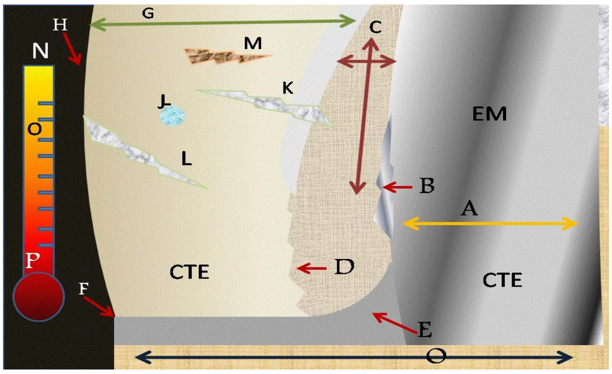

Figure 2. Micro-level variables affecting fracture resistance of metal-ceramic Restorations. These include: Metal variables (thickness *A*, roughness *B*); Oxide layer variables (presence, thickness, uniformity *C*, surface roughness *D*, wetting ability); Metal-porcelain junction variables (rounded internal angles *E*, 90-degree or a greater external angles at porcelain-metal junction *F*); Porcelain layer variables (various thickness at different locations not exceed 2 mm *G*; Smoothness and polishing of surface *H*); Physical properties (compatibility between coefficient of thermal expansion of metal and porcelain *CTE*, elastic modulus of metal *EM*, mechanical fatigue resistance of porcelain, static fatigue resistance of porcelain under humidity); Porcelain impurities (air voids *J*, cracks internal *K*, or external *L*, dust impurity *M*); Porcelain firing procedures (rate of cooling and heating *N*, Number of repeated firings *O*, excessively high oven temperatures *P*).

ramics and others. Straussberg *et al*. [71] said: "to obtain the optimum results inherent in porcelain-fused-to-gold restorations, the dentist must understand and respect the physical characteristics of the materials and guide the design and fabrication of the restoration so as to exploit their strengths and compensate for their weaknesses."

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