Review
Fracture reasons in ceramic-fused-to-metal restorations

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SUMMARY Ceramic-fused-to-metal restorations are widely used in dentistry with a high degree of general success. Fracture of the ceramic veneers as a result of oral function or trauma is not an uncommon problem in clinical practice. Although fractures of such restorations do not necessarily mean the failure of the restoration, the renewal process is both costly and time consuming and therefore remains a clinical problem. Fractures in the anterior region pose an aesthetic problem but when they are in the posterior, chewing function could also be affected. The published literature reveals that reasons for failures cover a wide spectrum from iatrogenic factors to laboratory mistakes or because of factors related to the inherent structure of the ceramics or simply to trauma.

KEYWORDS: fracture, ceramics

Introduction
Because of their excellent biocompatibility and superior aesthetic qualities, ceramic-fused-to-metal crowns and bridges are commonly applied in fixed prosthodontics. Despite the increased effort to improve the bond strength between the ceramic and the metal substrate, on occasion, fractures of ceramic veneers still occur under clinical conditions. The reasons for such failures are frequently repeated stresses and strains during chewing function or trauma. Clinical studies indicated that the prevalence of ceramic fractures ranged between 5 and 10% over 10 years of use (Coornaert, Adrians & de Boever, 1984).

Ceramic fractures are serious and costly problems in dentistry. Moreover, they pose an aesthetic and functional dilemma both for the patient and the dentist. Therefore the intent of this paper is to review the published literature on the reasons for fractures, concentrating on the data obtained both from in vitro and in vivo studies.

Failure rates
Many patients are still in need of fixed restoration replacements as a result of some failures in those restorations. Only a few studies in the literature have dealt with the survival rates of metal–ceramic restorations.

In a clinical follow-up study by Coornaert et al. (1984), the prevalence of fractures in metal–ceramic crowns was found to be approximately 5% over 10 years of function. Strub, Stiffler and Schärer (1988) observed a failure rate of metal–ceramic restorations of only between 1 and 3% over 5 years. Studies by Karlsson (1986) revealed a 93% success rate for fixed bridge restorations during a 10-year period, while Palmqvist and Swartz (1993) reported a 79% success rate over an 18–23-year period. The survival rates obtained by Glantz et al. (1993) as a function of time between 1979 and 1994 indicated that most of the debondings occurred over 15 years and almost all recorded dislodgements were observed within 5 years of placement. Subsequent clinical results from Hankinson and Cappetta (1994) and Kelsey et al. (1995) exhibited 2–4% failure rates after 2 years of function, rising from 20 to 25% after 4–5 years because of consistent repeating occlusal contacts.

In another clinical retrospective analysis, 1219 three-unit fixed bridges and 1618 single crowns in the anterior region were evaluated between 1969 and 1989 (Kerschbaum, Seth & Teeuwen, 1997). The results
of the study supported the superiority of metal–ceramic systems over acrylic-veneered crowns with 2–4% failure rates after 2 years of function. Statistical analysis however, showed that after 10 years, 88.7% of the metal–ceramic crowns and 80.2% of the metal–ceramic bridges were still in function.

Overall survival rate of metal–ceramic restorations demonstrate a paradox in the different survival rate values in the literature. It is well recognized that many factors are involved in the success rate assessments of fixed partial dentures limiting the longevity of the restorations.

Factors affecting failure

Failure of the restorations is in fact a multifactorial problem which could be related to a combination of different reasons. Optimization of the metal–ceramic restorations requires knowledge of the failure phenomena. Numerous studies over the years have focused on reasons for failure.

Mechanical failures of metal–ceramic systems are not surprising considering the vast differences in modulus between the metal and ceramic materials. When feldspathic dental porcelain is cooled, the leucite crystals contract more than the surrounding glass matrix leading to the development of tangential compressive stresses around the leucite particles as well as to microcracks within and around the crystals (Hasselman & Fulathy, 1966; MacKert, 1988; Anusavice & Zhang, 1998; Denry, Holloway & Rosentiel, 1998).

Some studies attributed the reasons for failures to the environmental factors and particularly to the moisture. Twenty to 30% reduction in metal–ceramic strength was found in a moist environment (Sherill & O’Brein, 1974). Michalske and Freiman (1982) indicated that silicate bonds in the glassy ceramic matrix are susceptible to hydrolysis by environmental moisture in the presence of mechanical stress. The porcelain restoration functions in a moist environment, which may allow static fatigue to cause the propagation of fractures along the microcracks resulting in failure of the restoration. The environment of the oral cavity was found to aggravate the strength of dental ceramics. The silicon–oxygen bond become weaker between the metal and ceramic in the presence of moisture which abet failure in many ways primarily because of the water propagation at the crack tip (Dauskardt, Marshall & Ritchie, 1990). In the oral environment, the influence of water and fatigue, caused by cyclic loading such as mastication, are considered important factors in the durability of metal–ceramic restorations. Yet, the effect of other artificial environmental factors such as saliva or different kinds of drinks needs to be studied.

The most frequent reasons for ceramic failures are related to the cracks within the ceramic. The minute scratches present on the surfaces of nearly all materials sometimes behave as sharp notches whose tips are as narrow as the spacing between atoms in the materials. Thus, the stress concentration at the tips of these minute scratches causes the stress to reach the theoretical strength of the material at relatively low average stress. When the theoretical strength of the material is exceeded at the tip of the notch, the bond at the notch tip breaks. As the crack propagates through the material, the stress concentration is maintained at the crack tip until the crack moves completely through the material (Lamon & Evans, 1983). Long antero-posterior metal substructure also flexes under heavy or complex loading causing porcelain fracture (Reuter & Brose, 1984). The cracks existing within the ceramic are important issues to be considered in the survival of fixed partial dentures. Especially in long span bridges, crack propagation might then result in the catastrophic failure of the restoration.

It was also noted that other reasons for the ceramic fractures are technical mistakes during the preparation of the restorations and claimed that occasional presence of pores inside the ceramic could account for their weakness and eventual fracture at that site (Oram & Cruickshank-Boyd, 1984). The same results were also found by Øilo (1988) who agreed that such mistakes markedly increase the failures.

Further studies demonstrated the importance of microcracks existing in the ceramic. Microcracks in ceramic could also be caused by the condensation, melting, and sintering process of the ceramics on metal because of thermal coefficient differences (Yamamoto, 1989). Faulty design of the metal substructure, incompatible thermal coefficients of expansion between the metal substructure and ceramic, excessive porcelain thickness with inadequate metal support, technical flaws in the porcelain application, occlusal forces or trauma were also included as the failure reasons (Diaz-Arnold, Schneider & Aquilino, 1989). Because of the heterogeneous nature of many dental materials, they are likely to contain defects or flaws in various amounts and sizes. Such flaws remain at fixed length unless...
under load but then they become unstable and propagate, catastrophically culminating in fracture. Small changes in microstructure or surface treatment can lead to drastic alterations in service life of fixed restorations and repeated stresses and strains can cause slow crack growth and mechanical fatigue. Even a single load cycle can produce measurable cracking at the contact area and damage accumulation during load cycling (Chadwick, Mason & Sharp, 1993; White et al., 1995). In order to minimize the formation of microcracks a fairly uniform thickness was recommended, which may occur during the firing of the ceramic. Avoidance of acute line angled preparations was advised as they enhance the formation of microcracks within the porcelain during the firing procedures (Burke, 1996). The results of these studies definitely favoured the requirement of technical skill and meticulous work in ceramic build-up. Clinical part of the process could have been performed ideally however, when high level of skill in ceramic build-up is not performed, the failure of the restoration could be inevitable. The important question is whether it would be possible to avoid any flaws during ceramic build-up.

Widerhorn (1968, 1974) stressed that during actual masticatory conditions, restorations are subject to repeated loading over long periods, with superposed tangential motion and further claimed that, especially in chemically active aqueous environments, this could greatly exacerbate damage build-up. He stated that the ceramic fracture process might be accelerated by the environment. It was reported that facings may crack, be fractured or damaged as a result of trauma, parafunctional occlusion or inadequate retention between the veneer and the metal (Farah & Craig, 1975). In clinical practice however, the magnitude and direction of masticatory forces cannot be controlled. Studies that involve forces from one direction can give the clinicians limited information which may not always be possible to adapt real life.

Mechanical fatigue of ceramics on the other hand, is probably governed by several mechanisms which are related to material properties including microstructure, crack length and fracture toughness, as well as to applied stress intensity (Ban & Anusavice, 1990). Evans et al. (1990) indicated that every effort should be made to minimize air entrapment between ceramic particles as porosity does occur during ceramic application and can impair aesthetics as well as promote fracture. Properties of resin adhesives, cementation agents, preparation designs, voids in cement layers, and thickness of the ceramic restorations were reported to affect the fracture resistance as well (Tsai et al., 1998). One of the most popular test methods is mathematical modelling in material research. Although such modelling has some limitations and little is known on its applicability to clinical situations, in a finite element analysis, it was found that the presence of a void in the ceramic structure did have a significant effect on the fracture (Abu-Hassan, Abu-Hammad & Harrison, 1998).

Another reason for porcelain fracture was attributed to inadequate tooth preparation, which results in too little interocclusal space for the metal substructure and porcelain. It was concluded that the improper design of the restoration for the occlusion is the major cause of failure (Creugers, Snoek & Käyser, 1992). The possible failure of ceramics was sometimes attributed to inadequately registered occlusion, material type, spanning of the restoration or inadequate marginal adaptation (Niedermeier et al., 1998). On the basis of this evidence, clinicians should identify and address the reasons for their failures in practice. When occlusion is not registered correctly and articulation is not checked properly, the premature contacts would act as stress bearing zones on the ceramics.

The fatigue failure is preceded by a combination of crack initiation and crack propagation. Finally catastrophic failure occurs in the form of fracture. Llobell et al. (1992) described the reasons for intraoral ceramic fracture as impact load, fatigue load, improper design, microdefects within the material, and added that clinically, mastication, parafunction and intraoral occlusal forces create repetitive dynamic loading. It was emphasized that fatigue is of considerable importance for metal–ceramic restorations which are subjected to small alternating forces during mastication.

Amorphous materials like glasses or glassy materials do not possess an ordered crystalline structure as do metals. Bertolotti (1997) described the reasons in detail why ceramic materials do not yield in the same manner as metals. Dislocations of a crystalline lattice do not exist in glassy materials and they have no mechanism for yielding without fracture. Dislocations exist in crystalline ceramic materials, but their mobility is severely limited. The energy required to do this is so large that dislocations are essentially immobile in crystalline ceramic materials.

Stress direction is another contributory factor for failure as sometimes failure occurs at sites of relatively
low local stress merely because there is a particularly large flaw oriented in a stress field which is ideal for causing fractures. The possible sites from which failure may start were found to be highly unpredictable, since this depends on flaw size and is related to the stress distribution (White & Li, 1997). High biting forces, destructive premature contacts and common beverages with low pH ranges were reported to cause glass-containing dental restorations to break down (Anusavice & Zhang, 1998). Although these data appear to document the importance of bite forces in failures, it is apparently not possible to quantify them during mastication.

The majority of the ceramic fractures were observed to occur during normal chewing function followed by either trauma or some kinds of accidents being mostly in the anterior region (Özcan, 1999; Özcan & Niedermeier, 2001). The findings of these studies clearly indicate that the reasons for ceramic failures might be also external factors other than technical reasons in real life.

Complications involving fixed partial dentures can also occur during the pre-prosthetic preparation phase. Raustia, Näpänkangas and Salonen (1998) noted that the clinical skill of the dentist or dental student is extremely important.

Conclusions
Fracture of porcelain is often considered an emergency treatment and the restoration process can present a difficult challenge to the dentist. Clinical studies indicated that the prevalence of ceramic fractures ranged between 5 and 10% over 10 years of use (Coornaert et al., 1984). There is consistent epidemiological evidence that mechanical failure of a dental prosthesis occurs after a number of years of service. Therefore, prosthodontic structures typically do not fail as a consequence of a single episode of stress application, but rather as the cumulative effect of a large number of comparatively small loadings.

Because of the nature of the porcelain processing, new porcelain cannot be added to an existing restoration intraorally. The manual fabrication of metal frameworks and the porcelain veneers is time consuming and requires a high level of skill (Freilich et al., 1998). It is an unpleasant experience for the patient and arduous for the dentist to remove these restorations from the mouth. Replacement of a failed restoration is not necessarily the most practical solution because of the obviously substantial costs and the complex nature of the restoration (Fan, 1991).

The complexities of the oral environment and varied surface topography of dental restorations make it difficult to precisely define the magnitude and mode of stresses precipitating clinical fracture. The laboratory cannot reproduce intraoral variables and the complexities of the oral environment. When the crowns are cemented intraorally, factors other than inherent mechanical strength of the materials come into play. Under continuous application of the mechanical environmental loads, progressive degradation may lead to crack initiation and growth and ultimately to a catastrophic failure of the restoration.

Although failures of ceramic-fused-metal restorations can be overcome by either some repair techniques or renewal of the restoration, it is beneficial to know the reasons for the failures, especially those because of iatrogenic or technical mistakes, which would help to increase the service time of such restorations.

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