Failure Modes and Fracture Origins of Porcelain Veneers on Bilayer Dental Crowns

Yihong Liu, PhD, DDS[a]/Guanghua Liu, PhD[b]/Yong Wang, PhD[c]/
James Zhijian Shen, PhD[d]/Hailan Feng, PhD, DDS[e]

The aims of this study were to determine the fracture origins and crack paths in the porcelain of clinically failed bilayer ceramic restorations and to reveal the correlation between the porcelain failures and material properties. Three clinically failed crowns of each material (bilayer zirconia crowns, galvano-ceramic crowns, and porcelain-fused-to-metal crowns) were collected and underwent failure analysis. The fractures found in porcelain veneers showed several characteristics including wear, Hertzian cone crack, chipping off, and delamination. The results indicated that the fracture origins and features of the porcelain in bilayer ceramic restorations might be affected by the rigidity of core materials and thickness of copings. *Int J Prosthodont 2014;27:147–150. doi: 10.11607/ijp.3608*

In practice, porcelain flaking and chipping are the most frequently reported failures of bilayer ceramic restorations with metal and zirconia copings.[1] To improve the mechanical reliability of bilayer restorations, comprehensive research is needed to investigate the porcelain damage. It has been demonstrated that the mechanical performance of bilayer crowns relies on the intrinsic mechanical properties and the property matching between the core and porcelain.[2] Zhang et al[3] stated that Hertzian cone cracks were typical fatigue damages of brittle materials, such as porcelain, as the result of cyclic compressive stress. The Hertzian crack began as a surface ring crack outside the elastic contact. When the stress reached a critical load, the crack propagated downward and flared outward within a modest tensile field, then turned into a stable and truncated cone configuration. Furthermore, the ceramic wear occurred primarily as abrasion or microfracture. This generated subsurface intergranular cracking and led to subsequent grain pullouts. The aims of this study were to disclose the fracture origins and crack paths of clinically failed bilayer crowns and to reveal the correlation between the porcelain failures and the material properties using standard fractography analysis.[4,5]

Materials and Methods

Three clinically failed bilayer ceramic crowns of each core material were observed (Table 1). The cores were zirconia (Procera Allzircon, Nobel Biocare), galvano-gold (AGC, Weiland Dental and Technik), nickel-chromium alloy (NiCr) (Heraeus Dental), and noble metal alloy (Bio Herador N, Heraeus Dental). All crowns had occlusal contact with natural teeth in the opposing arch. All patients returned to the clinic immediately after the failure of their restoration. The failed restorations were collected after falling off or being carefully removed by the clinician.

The fracture surfaces of failed crowns were preliminarily examined using an optical microscope (Motic k400, Preiser Scientific), followed by thorough investigation using scanning electron microscopes (SEM, JEOL JSM-820 and JSM-7000F, Jeol; S-4300, Hitachi). Standard fractography characterization procedures were performed to analyze the fracture origins and features.

[a]Associate Professor, Department of General Dentistry, Peking University School and Hospital of Stomatology, Beijing, China.
[b]Associate Professor, Technical Institute of Physics and Chemistry, Chinese Academy of Sciences, Beijing, China.
[c]Professor, National Engineering Laboratory for Digital and Material Technology of Stomatology, Peking University School and Hospital of Stomatology, Beijing, China.
[d]Professor, Department of Materials and Environmental Chemistry, Stockholm University Arrhenius Laboratory, Stockholm University, Stockholm, Sweden.
[e]Professor, Department of Prosthetics, Peking University School and Hospital of Stomatology, Beijing, China.

Correspondence to: *Dr Yihong Liu, Department of General Dentistry, Peking University School and Hospital of Stomatology, Zhongguancun Nandajie No22, Haidian District, Beijing 100081, China. Fax: +86 10 62170009. Email: kqliuyh@163.com*

Table 1 Position, Time in Use, and Porcelain Fracture Features of Clinically Failed Bilayer Crowns

No.	Core material	Crown position	In vivo duration (mo)	Fracture feature
11	Zirconia	Maxillary molar	3	Porcelain chipping off
12	Zirconia	Maxillary molar	6	Porcelain delamination
13	Zirconia	Mandibular molar	6	Porcelain delamination
21	Noble alloy	Maxillary premolar	24	Porcelain chipping off
22	Noble alloy	Maxillary molar	15	Porcelain chipping off
23	Noble alloy	Mandibular molar	36	Porcelain delamination
31	Ni-Cr alloy	Mandibular molar	12	Porcelain delamination
32	Ni-Cr alloy	Mandibular molar	24	Porcelain delamination
33	Ni-Cr alloy	Maxillary molar	24	Porcelain chipping off
41	Galvano-gold	Maxillary incisor	12	Porcelain delamination
42	Galvano-gold	Maxillary incisor	24	Porcelain delamination
43	Galvano-gold	Mandibular molar	12	Porcelain delamination

Fig 1 Porcelain wear scars on the **(a)** occlusal surface of an Ni-Cr coping crown (mandibular molar), **(b)** occlusal surface of a zirconia crown (maxillary molar), and **(c)** lingual surface of a galvano-ceramic crown (maxillary incisor).

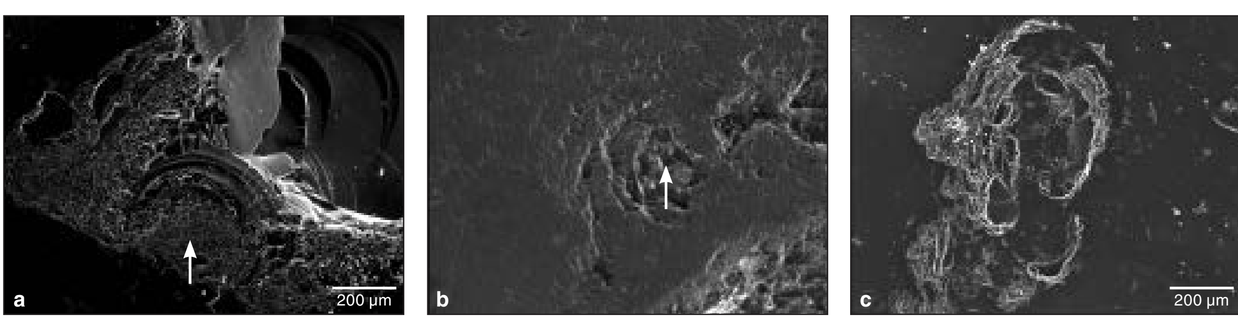


Fig 2 Hertzian cone cracks observed in the porcelain: **(a)** typical Hertzian cone cracks observed on the occlusal surface of a maxillary molar zirconia crown and **(b)** the lingual surface of a maxillary incisor galvano-ceramic crown. The origins of the Hertzian cone cracks are marked by arrows. **(c)** The multiorigin cracks presented on the occlusal surface of a maxillary molar zirconia crown.

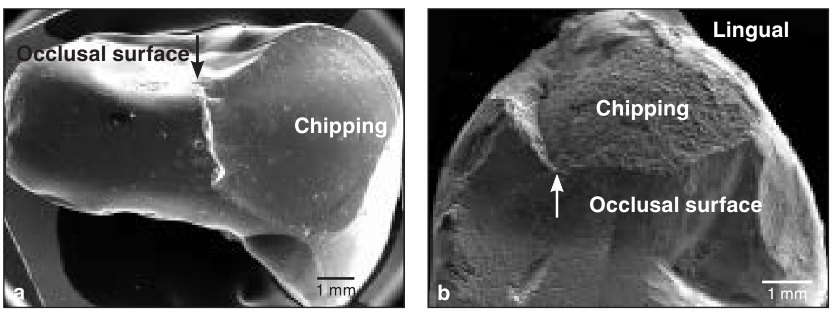
Results

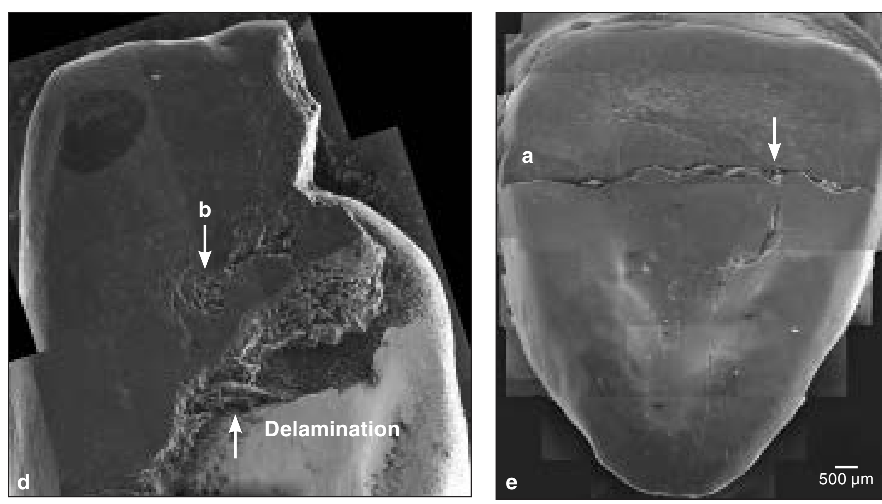
Several typical damage features were found in the porcelain. Wear scars were found on the surfaces of porcelain in all restorations, presenting as microcracks, roughness, and mass loss (Fig 1).

Hertzian cone cracks and multiorigin cracks were characteristic features visible on the occlusal surfaces of molar crowns and on the lingual surfaces of incisor crowns (Fig 2).

Porcelain chipping off was detected in four crowns with copings made of noble metal alloy, Ni-Cr alloy,

Fig 3 Fractography overviews by low magnification SEM micrographs of the failed bilayer ceramic crowns. **(a)** The porcelain chipping damage was observed on the occlusal surface of a maxillary molar zirconia crown. Arrow indicates the fracture origin of a Hertzian cone crack. **(b)** The lingual part of a maxillary premolar noble alloy porcelain-fused-to-metal crown was illustrated by merging 15 individual SEM images. Arrow indicates the origin of a Hertzian cone crack. **(c)** The distal part of the mandibular molar Ni-Cr alloy porcelain-fused-to-metal crown was shown by merging 20 SEM images. The fracture origin was marked with an arrow. **(d)** The lingual side of a maxillary incisor galvano-ceramic crown was illustrated by merging 13 SEM images. The fracture origin was marked by arrow "a," and a Hertzian cone crack was marked by arrow "b." **(e)** The lingual side of a maxillary incisor galvano-ceramic crown was illustrated by merging 30 SEM images. The porcelain chipping was marked by "a," and porcelain fracture was marked by an arrow.





and zirconia. Figure 3a shows the fractured surface of a maxillary molar zirconia crown after porcelain chipping off. The fracture was initiated by Hertzian cone crack at the distal marginal ridge on the occlusal surface. As seen in Fig 3b, Hertzian cone crack yielded the porcelain chipping on the occlusal surface of a premolar noble metal alloy crown.

Porcelain delaminations originating at the occlusal contact were observed on noble metal alloy porcelain-fused-to-metal and zirconia crowns. As shown in Fig 3c, the porcelain delaminations originated from multiorigin cracks on the occlusal surface of a mandibular molar Ni-Cr coping crown.

In contrast, the porcelain delaminations on the galvano crowns originated from the porcelain-core interface. The clear arrest lines on the facture surface of a maxillary incisor galvano crown indicated that the porcelain fracture originated from the porcelain-core interface (Fig 3d). High magnification observation revealed that the microcracks were only detected at the porcelain-core interface (Fig 4a). The same fracture origin and crack path were also found in another incisor galvano crown (Fig 3e). The arrest lines occurred on the concave side toward the core-porcelain interface (Fig 4b). Additionally, wake hackles were observed on the side away from the inner core (Fig 4c).

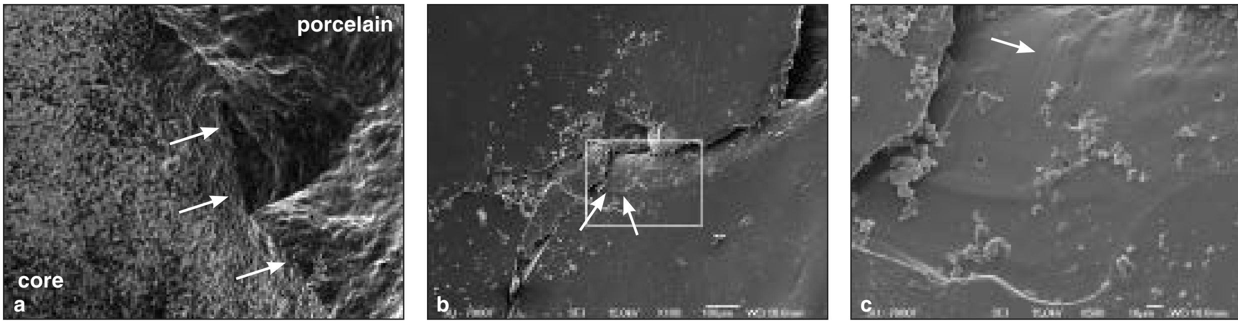


Fig 4 Fracture surfaces of galvano-ceramic crowns revealing interface fracture origins. **(a)** The critical cracks at the porcelain-core interface are marked by arrows in a maxillary incisor crown. **(b)** The arrest lines occurred on the concave side toward the core-porcelain interface in the fracture area of a maxillary incisor crown. **(c)** The wake hackles *(arrow)* were observed on the side away from the inner core.

These features indicated that the porcelain fracture might have initiated at the core-porcelain interface.

Discussion

Hertzian cone cracks and multiorigin cracks, as well as porcelain wear, were initiated by cyclic compressive occlusal force. Once the cracks propagated through the porcelain, porcelain chipping off occurred. While the cracks spread along the porcelain-core interface, porcelain delaminations were unavoidable. Though the wear scars did not lead to porcelain fracture, the damage risk to both the restorations and natural teeth increased. Special care should be taken to improve the glaze performance of porcelain to reduce friction between the porcelain and natural teeth.

Microcracks at the porcelain-core interface were observed only in the galvano crowns. The formation of microcracks was initiated by the momentarily high tensile stress due to plastic deformation of galvano-gold copings, which relate to poor rigidity and strength, but add only 0.3 to 0.4 mm of thickness.

Conclusion

The results of this study indicated that the fracture origins and features of the porcelain in bilayer restorations might be affected by the rigidity of core materials and thickness of copings.

Acknowledgments

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