Fracture force for veneered materials on restorations measured by torsion testing

Fumihiko WATANABE1, Munetsugu SETO2, Kazuhiko UEDA1 and Makoto OZAWA1

1 Department of Crown and Bridge Prosthodontics, School of Life Dentistry at Niigata, The Nippon Dental University, 1-8 Hamaura-cho, Chuo-ku, Niigata 951-8580, Japan
2 Oral Implant Care Unit, Niigata Hospital, The Nippon Dental University, 1-8 Hamaura-cho, Chuo-ku, Niigata 951-8580, Japan
Corresponding author, Fumihiko WATANABE; E-mail: fumi@ngt.ndu.ac.jp

The torsional fracture strength at the interface between a base plate and veneering material was evaluated for three kinds of veneered restoration: porcelain fused to zirconia (PFZ), porcelain fused to metal (PFM), and composite resin veneered metal (CRVM). The metal and zirconia base plate (30×4×0.4 mm) were prepared and these plates were veneered as test specimens using each material to a total thickness of 1.2 mm. Torsional force was applied to each specimen using a rotational speed of 1.0 deg/min until the veneering material underwent fracture or exfoliation. The torsional fracture values were measured and the data were statistically analyzed using one-way ANOVA. The torsional fracture strength for PFZ, PFM, and CRVM was 3.0, 3.1, and 11.1 N·cm, respectively.

Keywords: Torsion test, Torsional fracture force, Porcelain fused to zirconia, Porcelain fused to metal, Composite resin veneered metal

INTRODUCTION

Several veneered and all-ceramic restorations are applied in daily clinical practice because they meet the aesthetic requirements desired in dentistry. Porcelain fused to metal (PFM), porcelain fused to zirconia (PFZ), and composite resin veneered metal (CRVM) restorations have been used in response to the demand of aesthetic recovery. Further aesthetic requests and all-ceramic restoration based on zirconia have shown compatibility in recent years.

Many researchers have reported chipping, fracture, or exfoliation of the porcelain or composite resin of the veneering portion of restorations or fixed partial dentures (FPD) observed clinically, and they suggest the causes are vertical and horizontal loading or rotational torque during chewing, failure of the frame design and inadequate execution of laboratory steps1-5). In PFZ restorations, chipping of the veneering ceramic after three years occurs in 11–25% of all cases6-12). In contrast, veneer chipping with metal ceramic crowns is 3% after 15 years13). The failure rate for the veneering materials in zirconia-based restorations remains higher than that for veneered metallic restorations7,9,14).

Chips and fractures can occur as a result of excessive axis loading, horizontal loading, or rotational torque during functional activities such as chewing, or parafunctional activities such as prematurity contact and occlusal interference. Most ceramics are brittle, and the tensile stress caused by an occlusal load can lead to crack propagation15-17). It is thought that torsional stress occurs on the bridge of the cross arch while chewing. Even though several studies on shear strength testing have been reported18-22), no research papers have reported a torsional strength test for chipping or fractures of a veneered restoration. In the oral cavity, one possibility is that torsional force is applied in FPD with a cross-arch splint.

There have been several reports on veneer fracturing of ceramics and resins due to occlusal interference and prematurity contact, but reports on fracturing due to torsional stress are rare. This study hypothesizes that the difference between fracture/exfoliation and torsional stress of the veneered portion is related to the materials and restoration methods. In particular, PFZ has a compound structure of high and low fracture toughness materials. The difference in flexural strength between the zirconia and the veneering porcelain has been considered to be one reason for chipping. Consequently, in this present study, the null hypothesis was that the torsional fracture force of the veneering porcelain for PFZ was lower than that for PFM and CRVM. The purpose of this research is to compare the torsional fracture of the veneering material at the interface between the veneering and base plate materials by using veneered plates.

MATERIALS AND METHODS

Three kinds of test specimens, zirconia plate/porcelain, metal plate/porcelain, and metal plate/composite resin were prepared to correspond to PFZ, PFM, and CRVM, respectively. Each specimen consisted of a 5×30×0.4 mm (t×l×w) base plate and veneering material. The veneering material for the zirconia (Cercon, Dentsply-Sankin, Hanau, Germany), Ceramic Gold Extra (Shofu, Kyoto, Japan) and Type IV Casting Gold (GC, Tokyo Japan) base plates was porcelain (Vintage ZR, Shofu), porcelain (Vintage, Shofu), and composite resin (Epricord, Kuraray Noritake Dental, Tokyo, Japan), respectively (Table 1). PFZ

For the fusing of porcelain to a zirconia base plate, a Multi-matte Touch & Press (Dentsply-Sankin) was used.
Table 1  Materials used in the present study

| Materials                                      | Commodity name: batch number               | Used part |
|------------------------------------------------|--------------------------------------------|-----------|
| Porcelain fused to zirconia (PFZ)              | Vintage ZR (Shofu, Kyoto, Japan)           |           |
|                                                 | Opeque: 32636                              |           |
|                                                 | Body: 67708                                |           |
|                                                 | Enamel: 110908                             | Veneered  |
| Cercon Basecolorld: 18010001                   |                                            | Frame     |
| Porcelain fused to metal (PFM)                 | Vintage (Shofu)                            |           |
|                                                 | Base Opeque: 110962                        |           |
|                                                 | Shade Opeque: 090952                       |           |
|                                                 | Body: 0.90905                              |           |
|                                                 | Enamel: 110908                             |           |
| Cercon Basecolorld: 18010001                   |                                            | Frame     |
| Composite resin veneered metal (CRVM)          | Epuricoad (Kuraray Noritake Dental, Tokyo, Japan) |           |
|                                                 | Opeque: 00105                              |           |
|                                                 | Dentin: 00325A                             |           |
|                                                 | Wet Enamel: 00121A                         |           |
| Type IV Casting Gold (GC, Tokyo, Japan): 1101182|                                            | Frame     |

The zirconia base plate was sandblasted with 50-µm alumina and after 5 min of ultrasonic cleaning, porcelain was built up and fused on it. The fusing schedule was conducted according to the manufacturer’s instructions.

**PFM**

A wax pattern was fabricated and invested using investment materials depending on the manufacturer’s instructions and casted using Ceramic Gold Extra. The metal base plate was processed by heat treatment. After ultrasonic washing, the metal base plate was finished to established measurements using J1000 waterproof sand paper.

A KDF Master S (Denken-Highdental, Kyoto, Japan) was used to fuse the porcelain to the metal base plate of PFM. The plate was sandblasted with 50-µm alumina and then ultrasonically cleaned for 5 min. The plate was degassed at 950°C for 10 min and the porcelain was fused on it in accordance with the manufacturer’s instructions.

**CRVM**

A wax pattern was produced and 150-µm retention beads (Shofu) were used for the veneering surface. The pattern was invested using investment materials depending on the manufacturer’s instructions and casted using Type IV casting gold. The base plate metal was treated with heat.

For composir resin veneering, a light-curing unit (α-LIGHT V, Morita, Osaka, Japan) was used. After casting, the Type IV casting gold metal base plate was ultrasonically cleaned for 5 min. Then, metal primer (Metalink, Shofu) was applied and the composite resin was polymerized according to the manufacturer’s instructions. The veneered thickness of the specimens was subsequently adjusted to 1.2±0.01 mm using J1000 waterproof sand paper (Fig. 1).

Six specimens were prepared for each group. A torsion testing device (AG-XR, Shimadzu, Kyoto, Japan) was used for the experiments (Fig. 2). Using the same method as Seto and Watanabe²⁸, both ends of the test specimen were secured by a three-jaw scroll chuck structure. One end of the test specimen was fixed and the
other end was rotated, and torsional stress was applied until breakdown occurred. A specimen was mounted on the device and the fracture force was measured at a rotational speed of 1.0 deg/min until the veneering material fractured or exfoliated. The maximum capacity of the torsional torque was 50 N·m.

Each mean value was calculated. The data were statistically analyzed by one-way ANOVA. These data were calculated and compared using Tukey HDS. Fractured specimens were observed with a microscope. The fractured portions were ultrasonically cleaned in distilled water for 3 min, sputtered with Pt-Pd to a thickness of 90 Å, and then examined using scanning electron microscopy (SEM).

**RESULTS**

*Torsional strength testing*

The torsional fracture force of the veneering materials was 3.0, 3.1, and 11.1 N·cm for PFZ, PFM, and CRVM, respectively (Fig. 3). Although a statistically significant difference was observed in the strength between CRVM and PFM, PFZ, there was no difference between PFM and PFZ ($p<0.01$). The fracture force of the CRVM exhibited the highest value. Figure 4 shows the rotational degree until the veneering part was fractured. The torsional angle for CRVM, PFM, and PFZ was 20.4°, 6.5° and 3.9°.
respectively. There was a significant difference between the composite resin veneered and the porcelain veneered specimens \((p<0.01)\).

**SEM observations**

Figure 5 shows a photograph of a fractured CRVM specimen. The metal plate is transformed and deformed, and the composite resin part is exfoliated at the interface between the retention beads and the opaque porcelain of the composite. Figure 6 shows SEM images of the CRVM specimen. The composite resin is partially fractured at the interface of the retention beads by the torsional force.

It is likely that the opaque resin was cohesive at the interface between the metal base plate and the retention beads. Figure 7 shows a photograph of a fractured PFM specimen. The porcelain is completely exfoliated at the interface between the opaque porcelain and the metal. Even though porcelain is completely exfoliated from metal frame, opaque porcelain remains at the metal surface (Fig. 8). Figure 9 shows a photograph of a fractured PFZ specimen. Approximately fifty percent of the veneered porcelain is exfoliated along the torsion direction. The SEM image presented in Fig. 10 shows exfoliated veneering porcelain on the PFZ specimen. The
porcelain is exfoliated from the interface completely, although remnants of porcelain can be recognized at the surface of zirconia plate.

**DISCUSSION**

**Testing methodology**

In past tests on dental restoration materials, bending and tensile tests have been conducted with metal, ceramics, polymers, *etc.*\(^{19,24-26}\). Although it has been reported in the literature that torsional stress resulting from a combination of bending and pulling occurs in the oral cavity, no test has been performed to verify this.

When a fixed partial denture is fitted in the mouth, shearing and bending stress are applied to it\(^{27-29}\), and this combination stress is believed to result in torsion stress. In the present study, a torsion testing device was used to measure the adhesive strength with respect to torsion at the interface between the veneering material and the base material. In addition, preparing the experimental samples with a plate structure similar to veneer restorations used in clinical practice allowed simplification of the experimental system. In the past, studies of adhesion between the veneer restoration and the core material have mainly used shearing adhesion tests\(^{19,27}\) or tension tests\(^{27,28}\). However, such testing methodology cannot take into account the elasticity of the materials. While the use of bending tests\(^{29}\) allows elasticity to be included in the analysis, torsion stress, which is believed to occur within the mouth, cannot be included.

In the present study, the shape of the specimens were simplified, and they conformed to the fabrication used clinically. This recreated testing conditions that more closely resembled the oral environment and permitted the elasticity characteristic of the material to be included in the analysis.

**Strength with respect to torsion and fracture type**

Shearing tests using conventional methodology have shown roughly the same adhesive strength for PFM and PFZ\(^{29}\), and a similar result was found in the tests in the present study. Most samples of the fracture surface showed partial detachment of the porcelain from either the fixed side or the rotating side of the torsion testing device, and chipping occurred. CRVM showed vastly higher fracture force with respect to torsion stress than PFM and PFZ. This was due to the differences in the veneer, because porcelain is a very brittle material with little elasticity, so detachment or fracture of the veneer occurs at the yield point on the stress-strain curve. In addition, differences in the Young’s modulus for the porcelain and the zirconia or the metal base plate probably affected the results.

Torsion and bending do not easily lead to fracture if the elasticity of the material is large, and fracturing is likely to occur if the elastic modulus is small. However, in this experiment, because the deflection occurred in
the test piece due to the application of the torsional stress, it is considered that the material having a low elastic coefficient exhibited a higher value in this experiment. Thus, ceramics such as zirconia and porcelain are more prone to fracturing because their elastic modulus is higher than that of resin and larger than that of metal. In the case of CRVM, the resin of the base plate metal and the veneering resin are mechanically bonded, so it showed high torsional force. On the other hand, in the case of PFM and PFZ, the base plate and porcelain are chemically bonded, and a peeling force acts on the base plate and the veneering portion during the torsion test, but because it is chemically attached at the interface, destruction occurs at the same part. In the case of CRVM, the resin twists in the same direction as the base plate, but for PFM and PFZ it is thought that the porcelain was broken by shear force. Based on the above discussion, composite resin with larger flexural strength. In other words, it influence that the deflection of the veneer, the fracture toughness, and the elastic modulus are strong against torsion. At the same time, while detachment of the veneer occurred with CRVM, which is elastic, there was no fracture. This was probably the effect of the mechanical interlocking strength imparted by the retention beads, which gave high adhesive strength. Jones et al. carried out adhesive shear tests of PFM and CRVM, and they reported higher adhesive strength for PFM, a result that differs from the present study. This is probably due to differences in the testing methodology. In shearing tests, there is a stress concentration at the weighted side. The stress distribution in torsion tests with a square bar shows an increase from a stress value of 0 at the center to the maximum value at the outer edge due to the action of the torque. For this reason, in the plate shape used in the present study, the fixed side and the outer edge of the rotating side showed a greater stress concentration. These then became the starting points for fracture of the veneer, which occurred in such a way that one of the materials detached. In addition, we conjecture that the result is also due to differences in the elasticity of the materials and the differences in Young's modulus between the veneer and the base plate material.

The amount of rotation until fracture is 20.4°, 6.5°, and 3.9° for CRVM, PFM, and PFZ, respectively, which seems to be related to their elastic modulus. That is, casting gold and composite resin, with relatively high elastic modulus and bending strength, required larger angles until fracture.

In CRVM, the veneered resin is mechanically cured to the base plate metal, but in PFZ and PFM the veneered porcelain and the base plate zirconia and metal are fused chemically. Although fracturing occurred in the porcelain, it is presumed that the veneered resin exhibited peeling at the interface between the resin and the base plate metal. Due to the mechanical bonding in CRVM, the mechanical strength against twisting is high, but it seems that gradual peeling at the interface can be expected. It is thus necessary to elucidate the mechanism of this exfoliation, whereas in the chemically coupled porcelain, zirconia, porcelain and metal, it is necessary to clarify the mechanism of delamination by torsional stress and the fracture form at the interface.

CONCLUSIONS

The fracture force of CRVM is higher than that of PFM and PFZ with respect to torsional forces. In the torsion testing performed in this study, the degree of rotation required until fracture of the CRVM was larger than that for PFM and PFZ.

ACKNOWLEDGMENTS

The authors acknowledge the Shofu company for providing zirconia materials used in this study. The authors report no conflicts of interest related to this study.

REFERENCES

1) Asaoka K. Transient and residual stress in porcelain/alloy strip for dental use as affected by tempering. JSME Int J, Ser. 1, Solid mechanics, Strength of materials 1991; 34: 156-162.
2) Thomson GA. Influence of relative layer height and testing method on the failure mode and origin in a bilayered dental ceramic composite. Dent Mater 2000; 16: 235-243.
3) Wakabayashi N, Anusavice KJ. Crack initiation modes in bilayered alumina/zirconia disk a function of core/veneer thickness ratio and supporting substrate stiffness. J Dent Res 2000; 79: 1398-1404.
4) Hermann I, Bhowmick S, Lawn BR. Role of core support material in veneer failure of brittle layer structures. J Biomed Mater Res Part B Appl Biomater 2007; 82: 115-121.
5) Florian B, Hans A, Daniel E, Wolfgang G. Effect of preparation design on the fracture resistance of zirconia crown copings. Dent Mater J 2008; 27: 362-367.
6) Vult von Steyern P, Carlson P, Nilner K. All-ceramic fixed partial dentures designed according to the DC-Zirkon technique. A 2-year clinical study. J Oral Rehabil 2005; 32: 180-187.
7) Raigrodski AJ, Chiche GJ, Potiket N, Hochstedler JL, Mohamed SE, Billiot S, Mercante DE. The efficacy of posterior three-unit zirconium-oxide-based ceramic fixed partial dental prostheses: a prospective clinical pilot study. J Prosthet Dent 2006; 96: 237-244.
8) Sailer I, Febré A, Filser F, Lüthy H, Gauckler LJ, Schöngruber P, Hämmerle CH. Prospective clinical study of zirconia posterior fixed partial dentures: 3-year follow-up. Quintessence Int 2006; 37: 685-693.
9) Sailer I, Febré A, Filser F, Gauckler LJ, Lüthy H, Hämmerle CH. Five-year clinical results of zirconia frameworks for posterior fixed partial dentures. Int J Prosthodont 2007; 20: 383-388.
10) Sailer I, Pjetursson BE, Zwahlen M, Hämmerle CH. A systematic review of the survival and complication rates of all-ceramic and metal-ceramic reconstructions after an observation period of at least 3 years. Part II: Fixed dental prostheses. Clin Oral Implants Res 2007; 18 Suppl 3: 86-96.
11) Pjetursson BE, Brägger U, Lang NP, Zwahlen M, Comparison of survival and complication rates of tooth-supported fixed dental prostheses (FDPs) and implant-supported FDPs and single crowns (SCs). Clin Oral Implants Res 2007; 18 Suppl 3: 97-113.
12) Tischert J, Schulze KA, Natt G, Latzke P, Heussen N, Spiekermann H. Clinical behavior of zirconia-based fixed
partial dentures made of DC-Zirkon: 3-year results. Int J Prosthodont 2008; 21: 217-222.

13) Walton TR. An up to 15-year longitudinal study of 515 metal-ceramic FPDs: Part 2. Modes of failure and influence of various clinical characteristics. Int J Prosthodont 2003; 16: 177-182.

14) Christensen RP, Ploeger BJ. A clinical comparison of zirconia, metal and alumina fixed-prosthesis frameworks veneered with layered or pressed ceramic: a three-year report. J Am Dent Assoc 2010; 141: 1317-1329.

15) Komine F, Tomic M, Gerds T, Strub JR. Influence of different adhesive resin cements on the fracture strength of aluminum oxide ceramic posterior crowns. J Prosthodont Dent 2004; 92: 359-364.

16) Sundh A, Sjogren G. A comparison of fracture strength of yttrium-oxide-partially-stabilized zirconia ceramic crowns with varying core thickness, shapes and veneer ceramics. J Oral Rehabil 2004; 31: 682-688.

17) Attia A, Abdelaziz KM, Freitag S, Kern M. Fracture load of composite resin and feldspathic all-ceramic CAD/CAM crowns. J Prosthodont Dent 2006; 95: 117-123.

18) Jones RM, Moore BK, Goodacre CJ, Munoz-Viveros CA. Microleakage and shear bond strength of resin and porcelain veneers bonded to cast alloys. J Prosthodont Dent 1991; 65: 221-228.

19) Al-Dohan HM, Yaman P, Dennison JB, Razzaq ME, Lang BR. Shear strength of core-veneer interface in bi-layered ceramics. J Prosthodont Dent 2004; 91: 349-355.

20) Dundar M, Ozcan M, Comlekoglou E, Gungor MA, Artunc C. Bond strengths of veneering ceramics to reinforced ceramic core materials. Int J Prosthodont 2005; 18: 71-72.

21) Dundar M, Ozcan M, Gokce B, Comlekoglou E, Leite F, Valandro LF. Comparison of two bond strength testing methodologies for bilayered all-ceramics. Dent Mater 2007; 23: 630-636.

22) Guess PC, Kulik S, Witkowski S, Wolkewitz M, Zhang Y, Strub JR. Shear bond strengths between different zirconia cores and veneering ceramics and their susceptibility to thermocycling. Dent Mater 2008; 24: 1556-1567.

23) Seto M, Watanabe F. Torsional test of material for dental restoration. Nihon Shika Riko Gakkaishi 2014; 33: 313-320. (In Japanese)

24) Van Noort R, Noroozi S, Howard IC, Cardew G. A critique of bond strength measurements. J Dent 1989; 17: 61-67.

25) Phrukkanon S, Burrow MF, Tyas MJ. The influence of cross-sectional shape and surface area on the microtensile bond test. Dent Mater 1998; 14: 212-221.

26) ISO. ISO 9693-1: Dentistry —Compatibility testing— Part 1: Metal-ceramic systems. Switzerland: International Organization for Standardization; 2012.

27) Zheng Z, Lin J, Shinya A, Matinlinna JP, Botelho MG, Shinya A. Finite element analysis to compare stress distribution of gold alloy, lithium-disilicate reinforced glass ceramic and zirconia based fixed partial denture. J Invest Clin Dent 2012; 3: 291-297.

28) Keulemans F, Shinya A, Lassila LV, Vallittu PK, Kleverlaan CJ, Feilzer AJ, De Moor RJ. Three-dimensional finite element analysis of anterior two-unit cantilever resin-bonded fixed dental prostheses. The Scientific World Journal 2015; 2015: 864389.

29) Lin J, Zheng Z, Shinya A, Matinlinna JP, Botelho MG, Shinya A. Structural stability of posterior retainer design for resin-bonded prostheses: a 3D finite element study. Odontology 2015; 103: 333-338.

30) Izumida A, Yoda M, Inagaki R, Toyoda J, Ishibashi M, Kasahara S, Kimura K. Mechanical properties of hard resins for crown and bridges. Nihon Hotetsu Shika Zasshi 2008; 52: 521-528.