Biaxial flexural strength of Turkom-Cera core compared to two other all-ceramic systems

Bandar Mohammed Abdullah AL-MAKRAMANI¹, Abdul Aziz Abdul RAZAK², Mohamed Ibrahim ABU-HASSAN³

¹- DDS, HDD, MDSc, PhD Candidate, Department of Conservative Dentistry, Faculty of Dentistry, University of Malaya, Kuala Lumpur, Malaysia.
²- DDS, MSc, PhD, Professor, Head, Biomaterials and Dental Technology Unit, Faculty of Dentistry, University of Malaya, Kuala Lumpur, Malaysia.
³- DDS, MDSc, PhD, Professor, Dean, Faculty of Dentistry, Universiti Teknologi MARA, Shah Alam, Malaysia.

Corresponding address: Bandar M.A. Al-Makramani, DDS, HDD, MDSc - Department of Conservative Dentistry - Faculty of Dentistry - University of Malaya - 50603 - Kuala Lumpur - Malaysia - Phone: 0060193024135 - Fax: 0060379674533 - e-mail: makramani@yahoo.com

Received: March 10, 2009 - Modification: August 7, 2009 - Accepted: August 11, 2009

ABSTRACT

Advances in all-ceramic systems have established predictable means of providing metal-free aesthetic and biocompatible materials. These materials must have sufficient strength to be a practical treatment alternative for the fabrication of crowns and fixed partial dentures. Objectives: The aim of this study was to compare the biaxial flexural strength of three core ceramic materials. Material and Methods: Three groups of 10 disc-shaped specimens (16 mm diameter x 1.2 mm thickness - in accordance with ISO-6872, 1995) were made from the following ceramic materials: Turkom-Cera Fused Alumina [(Turkom-Ceramic (M) Sdn Bhd, Puchong, Selangor, Malaysia)], In-Ceram (Vita Zahnfabrik, Bad Säckingen, Baden-Württemberg, Germany) and Vitadur-N (Vita Zahnfabrik, Bad Säckingen, Baden-Württemberg, Germany), which were sintered according to the manufacturer's recommendations. The specimens were subjected to biaxial flexural strength test in a universal testing machine at a crosshead speed of 0.5 mm/min. The definitive fracture load was recorded for each specimen and the biaxial flexural strength was calculated from an equation in accordance with ISO-6872. Results: The mean biaxial flexural strength values were: Turkom-Cera: 506.8±87.01 MPa, In-Ceram: 347.4±28.83 MPa and Vitadur-N: 128.7±12.72 MPa. The results were analyzed by the Levene’s test and Dunnett’s T3 post-hoc test (SPSS software V11.5.0 for Windows, SPSS, Chicago, IL, USA ) at a preset significance level of 5% because of unequal group variances (P<0.001). There was statistically significant difference between the three core ceramics (P<0.05). Turkom-Cera showed the highest biaxial flexural strength, followed by In-Ceram and Vitadur-N. Conclusions: Turkom-Cera core had significantly higher flexural strength than In-Ceram and Vitadur-N ceramic core materials.

Key words: Ceramics. Strength. Dental materials.

INTRODUCTION

In the last few years, numerous new dental restorative materials have been introduced in response to an increasing demand for esthetic and biocompatible materials¹.

The high-strength all-ceramic materials that are currently used in dentistry consist of alumina, zirconia, pressed, castable or machinable glass ceramics. Several developments have taken place in these areas resulting in the production of ceramic materials for clinical use. These include the aluminous porcelain crown (Vitadur, Vita Zahnfabrik, Bad Säckingen, Baden-Württemberg, Germany), the non shrink ceramic crown (Cerestore, Johnson and Johnson, East Windsor, NJ, USA), the castable mica glass-ceramic crown (Dicor, Caulk/Dentsply, Milford, DE, USA) and the leucite-reinforced glass ceramics (IPS Empress, Ivoclar Vivadent, Schaan, Liechtenstein)⁶,²⁰,²²,²⁶,³². All these all-ceramic systems exhibit low flexural strengths (100-150 MPa), which make them at risk of failure when used for the construction of either posterior crowns or fixed partial dentures¹¹,²¹,²³. Due to the relatively low strength of the early types of ceramics employed in the conventional porcelain jacket crowns, an alumina-reinforced porcelain core material was developed by McLean.
for the fabrication of such crowns. A veneer porcelain placed on a core containing approximately 50% fused alumina crystals, compared to the conventional feldspathic porcelain level of about 19%, resulted in a dental ceramic with flexural strength from 100 to 130 MPa.

The popularity of high-strength ceramic systems is increasing, and the range of their clinical indications is expanding constantly. Lithium disilicate ceramics (IPS Empress 2, Ivoclar Vivadent, Schaan, Liechtenstein), infiltrated alumina ceramic (In-Ceram Alumina, Vita Zahnfabrik, Bad Säckingen, Baden-Württemberg, Germany; Turkom-Cera), and zirconium oxide ceramic (Procera) are popular high-strength ceramic materials that offer favorable esthetic characteristics, mechanical properties and biocompatibility.

In-Ceram Alumina has a high strength ceramic core fabricated through the slip-casting technique. A slurry of densely packed Al2O3 (80-82 wt%) is applied and sintered to a refractory die at 1120°C for 10 h. This produces a porous skeleton of alumina particles which is infiltrated with a low-viscosity glass in a second firing at 1100°C for 4 h. This system is conventionally used as a core material in conjunction with a more translucent ceramic to enhance esthetic properties.

Advances in dental ceramics include the introduction of a high-strength all-ceramic core material (Turkom-Cera) containing primarily aluminum oxide (99.98%). A stone die is covered with a 0.1-mm-thick red plastic foil and dipped in the Turkom-Cera Alumina Gel (99.98%) following the manufacturer’s instructions. After drying of the alumina gel, the coping with the red plastic foil is removed from the die and sintered for 5 min at 1150°C. The sintered coping is crystal hardened in a second firing process using Turkom-Cera Crystal Powder for 30 min at 1150°C. Like all other infiltration ceramics, this core is then veneered with porcelain adjusted to have the correct coefficient of thermal expansion (6.5-7.2).

Many ceramics are currently available and marketed for use as dental crown and bridge materials. It has not been ascertain whether the properties of the newer dental materials enable their clinical use to be extended to crowns and bridges in the posterior region. The maximum biting forces that may occur in the posterior area vary between 300 and 880 N. Therefore, it is important for the posterior restorations to be able to withstand the maximum biting forces created in this region.

Although long-term clinical studies constitute the ultimate basis on which to reliably predict the long-term performance of such restorations, several physical and mechanical properties are essential to support the correct indication of these materials. Because of different compositions and manufacturing techniques, dental ceramics vary in their physical and mechanical properties. One important property is the strength of the materials, and specially the flexural strength, because of the brittle nature of ceramics. Therefore, the aim of this study was to evaluate the flexural strength of Turkom-Cera compared to two other all-ceramic materials.

MATERIAL AND METHODS

Materials
Three different types of ceramic materials, Turkom-Cera [(Turkom-Ceramic (M) Sdn. Bhd., Puchong, Selangor, Malaysia)], In-Ceram (Vita Zahnfabrik, Bad Säckingen, Baden-Württemberg, Germany) and Vitadur-N (Vita Zahnfabrik) were used in this study.

Preparation of disc-shaped specimens
Perspex split mold with five circular openings of 16 mm diameter and 2 mm thickness was used for the preparation of the Turkom-Cera disc specimens. The Turkom-Cera Alumina Gel was mixed to an optimum consistency and placed into the disc-shaped perspex mold. The Turkom-Cera Alumina Gel was left in the mold for 24 h. After drying of the alumina gel, the discs were taken from the mold and fired (sintered) in the furnace (Ivoclar Vivadent, Programat p300, Ivoclar Vivadent AG, Schaan, Liechtenstein) for 5 min at 1150°C. The Turkom-Cera Crystal Powder was mixed with water and the sintered discs were crystal-hardened in a second firing process in the same furnace for 30 min at 1150°C. After firing, the excess crystals were removed with a diamond bur. A total of 10 Turkom-Cera discs (16 mm diameter and 2 mm thickness) were fabricated.

Perspex split mold with an open top and bottom 5 circular openings (16 mm diameter and 2 mm thickness) was used for the preparation of the In-Ceram disc specimens. The mold was rested and secured on a base made from gypsum die material (Densite, Shofu Inc., Kyoto, Japan). The In-Ceram alumina slip was prepared by mixing In-Ceram alumina powder with In-Ceram mixing fluid and additive supplied by the manufacturer. The slip was poured into the mold and fired for 24 h. After drying, the In-Ceram alumina discs were taken from the mold and fired using the In-Ceramat furnace (Vita Zahnfabrik) for 6 h at 120°C and 4 h at 1120°C. The In-Ceram Glass Powder was mixed with water and the sintered In-Ceram alumina discs
were glass-infiltrated in a second firing process in the same furnace for 30 min at 200°C and 4 h at 1100°C. Excess glass was removed with a diamond bur. A total of 10 In-Ceram discs (16 mm diameter and 2 mm thickness) were fabricated.

According to the results of a preliminary study, Vitadur-N porcelain discs of initial diameter 18 mm shrunk to 15.5-16 mm in diameter when fired. Therefore, a brass split mold with five circular openings of 18 mm diameter was used for the preparation of the Vitadur-N disc specimens. Vitadur-N aluminous core porcelain powder was mixed with Vita modeling liquid P to an optimum slurry consistency. The slurry was placed into the disc-shaped brass mold and vibrated to reduce air bubbles. A brass compactor was also machined and used to condense the slurry into the mold in order to obtain flat surface. The condensed slurry was left in the mold for 30 min and excess liquid was blotted away with absorbent tissue. A layer of Vita Modisol (Vita Zahnfabrik) separating medium was applied to the mold before the porcelain mixture was poured to facilitate removal of the set porcelain without any distortion. The disc specimens were then fired according to the manufacturer’s recommendation in a Multimat-Touch vacuum furnace (Dentsply, Dreieich, Hessen, Germany). The furnace was programmed to give a temperature of 1120°C for 60 s under vacuum followed by a further 60 s at atmospheric pressure. A total of 10 Vitadur-N aluminous core porcelain discs with 15.5-16 mm diameter were fabricated.

**Grinding of specimens**

In order to meet the exact requirements of the biaxial testing protocol recommended by ISO¹⁶ (1995), all specimens were subsequently grounded to a parallel shape using the grinder/polisher machine (Metaserv 2000, Buehler, Coventry, West Midlands, UK). A custom made specimen holder made from aluminum was designed and used for the grinding purpose. Eight specimens were fixed into the specimen holder using modeling wax (Figure 1). The initial grinding was performed under running water using a diamond grinding disc with a grain size of 70 μm, followed by fine-grinding using a grain size of 30 μm. After that, the specimens were polished with a 15 μm diamond polishing paste on a polishing cloth for two min. They were then rinsed thoroughly with running water for 20 s and dried in air.

In compliance with ISO¹⁶ (1995), the specimens were trimmed to 1.2±0.2 mm in thickness with parallelism of ±0.05 mm measured using the digital caliper (Mitutoyo Corp, Tokyo, Japan).

**Biaxial flexural strength testing**

Piston-on-three-ball test was used for the testing. In order to carry out the test, a loading pin and mounting jig were designed and used with the Instron Testing Machine (Instron 4302, Instron Corporation, England). The loading pin was cylindrical in shape with a diameter of 1.6 mm. The mounting jig had a circular opening of 16 mm in diameter with three depressions positioned at equal
The specimens were placed in the mounting jig which ensured the same relation between the supports and the applied load for all specimens. The 1.6 mm diameter loading pin was mounted to the crosshead of the Instron Testing Machine and applied the load at the center of each specimen (Figure 2). The test was carried out at a crosshead speed of 0.5 mm/min. The definitive fracture load was recorded for each specimen and the biaxial flexural strength was calculated from the following equation:

\[ \text{Biaxial flexural strength} = -0.238 \times \frac{7P(X-Y)}{d^2}; \]

\[ X = (1+\nu)\ln\left(\frac{r_2}{r_3}\right)^2 + \left(\frac{1-\nu}{2}\right)\left(\frac{r_2}{r_3}\right)^2; \]

\[ Y = (1+\nu)\left[1+\ln\left(\frac{r_1}{r_3}\right)^2\right] + (1-\nu)\left(\frac{r_1}{r_3}\right)^2, \]

where \( P \) is the total load causing fracture (N), \( \nu \) is Poisson’s ratio (0.25), \( r_1 \) is the radius of the support circle (5.0 mm), \( r_2 \) is the radius of the loaded area (0.8 mm), \( r_3 \) is the radius of the specimen (8 mm), and \( d \) is the specimen thickness at the origin of fracture (mm).

Statistical analysis

The results of the study were statistically analyzed with the SPSS software (v. 11.5.0 for Windows, SPSS, Chicago, IL, USA) using Levene’s test and Dunnett’s T3 post-hoc test at a pre-set significance level of 5% to determine if significant differences between tests groups were related to the ceramic material used for each group.

RESULTS

The objective was to test if the mean biaxial flexural strengths of Turkom-Cera, In-Ceram and Vitadur-N differ from each other. The mean biaxial flexural strength and standard deviation of ten specimens were calculated for each of the three groups tested (Table 1). Because of violation of the assumption of homogeneous variances (Levene’s statistic=13.212, \( P<0.05 \)), multiple comparisons were performed with Dunnett’s T3 post-hoc test at a preset significance level of 5% (Table 2).

The mean biaxial flexural strength values for Turkom-Cera (506.8±87.01 MPa), In-Ceram (347.4±28.83 MPa) and Vitadur-N (128.7±12.72 MPa) differed significantly from each other (Table 2) (\( P<0.05 \)).

DISCUSSION

Strength is an important mechanical property that can assist in predicting the performance of brittle materials\(^3\). The uniaxial flexural strength tests, including three-point, and four-point bending tests, and biaxial bending tests are the most commonly applied methods for evaluating the strength of dental restorations\(^27,32,33,34\). For uniaxial flexural strength tests, the principal stress on the lower surfaces of the specimens is tensile, and it is usually responsible for crack initiation in brittle materials. However, undesirable edge fracture, which can increase the variance of the failure stress value, might occur.

The method adapted in this study was the one recommended by ISO\(^{16} \) (1995) since the test standardizes specimen thickness, diameter, shape and roughness. In addition, the measurement of the strength of brittle materials under biaxial

Table 1- Mean and standard deviation (SD) of biaxial flexural strength of the three groups

| Ceramic     | \( N \) | Mean  | SD    | 95% Confidence Interval for Mean |
|-------------|--------|-------|-------|---------------------------------|
|             |        |       |       | Lower Bound                     | Upper Bound |
| Turkom-Cera | 10     | 506.8 | 87.01 | 444.59                          | 569.08      |
| In-Ceram    | 10     | 347.4 | 28.83 | 326.73                          | 367.98      |
| Vitadur-N   | 10     | 128.7 | 12.72 | 119.64                          | 137.84      |

Table 2- Multiple comparisons between the three all-ceramic systems tested

| (I) Ceramic (J) Ceramic | Mean Diff. (I-J) | Standard Error | Significance | 95% Confidence Interval |
|-------------------------|------------------|----------------|--------------|------------------------|
|                         |                  |                |              | Lower Bound | Upper Bound |
| Turkom-Cera             | In-Ceram         | 159.5*         | 29.0         | .001       | 78.7        | 240.2      |
| Vitadur-N               | In-Ceram         | 378.1*         | 27.8         | .000       | 298.5       | 457.7      |
| In-Ceram                | Turkom-Cera      | -159.5*        | 29.0         | .001       | -240.2      | -78.7      |
| Vitadur-N               | Turkom-Cera      | 218.6*         | 10.0         | .000       | 191.4       | 245.9      |
| Vitadur-N               | In-Ceram         | -378.1*        | 28.0         | .000       | -457.7      | -298.5     |
| In-Ceram                | Turkom-Cera      | -218.6*        | 10.0         | .000       | -245.9      | -191.4     |

* Based on observed means, the mean difference is significant at the 0.05 level
flexural strength conditions rather than uniaxial flexural strength is often considered more reliable because the maximum tensile stresses occur within the central loading area and edge failures are eliminated. Therefore, the biaxial flexural test gave less variation in the strength data. According to ISO (1995), the biaxial flexural strength is determined by support of a disc specimen on three metal spheres positioned at equal distances from each other and from the center of the disc. The load is applied to the center of the opposite surface by a flat piston. The disc specimens can be easily made under typical restorative conditions. Furthermore, the flat surface of the test specimen can be easily controlled by conventional metallographic polishing methods and typical dental finishing techniques.

Different researchers have studied the biaxial flexural strength of In-Ceram core using the same methods as the current study. The biaxial flexural strength of In-Ceram has been found to be 337.5 MPa on the average (20, 28, 32). The mean biaxial flexural strength value for In-Ceram (347.4 MPa) obtained in the present study is in agreement with this result. The biaxial flexural strength of Vitadur-N core material has been investigated using the same methods as the current study and found to vary from 141.2 to 155 MPa (11, 12, 23). The mean biaxial flexural strength value for Vitadur-N (128.7 MPa) achieved in the current study is in agreement with these results.

The higher flexural strength obtained with Turkom-Cera and In-Ceram may be attributed to the following (7, 14, 25, 28, 30): 1. Decrease of the total porosity by initial firing (sintering) of Turkom-Cera alumina gel and In-Ceram alumina slip; 2. The alumina particles increase the strength of the material and limit potential sites for crack propagation; 3. Prevention of the growth of cracks by crack bridging, as the crystals and glass powders in combination with alumina may bridge the opening created by a crack after the crack front passes; 4. Compressive stresses, which further improve the strength, are also introduced due to the differences in the coefficient of thermal expansion of the alumina and crystals/glass.

Despite the high strength reported with high alumina-based ceramics, they are susceptible to fatigue failure that can considerably reduce their strength over time. In this study, the influence of fatigue in the oral cavity was not considered. Therefore, further studies are highly recommended to evaluate the fracture analysis and fatigue behavior of new dental ceramics.

CONCLUSION

In this study, the biaxial flexural strength of three all-ceramic core materials was tested in vitro. The new high-strength all-ceramic core material containing primarily aluminum oxide had significantly higher flexural strength (506.8±87.01 MPa) than the other ceramic core materials (In-Ceram: 347.4±28.83 MPa and Vitadur N: 128.7±12.72 MPa).

ACKNOWLEDGEMENTS

This study was supported by a grant (P019/2006C); University of Malaya, Kuala Lumpur, Malaysia. The authors thank Turkom-Ceramic (M) Sdn Bhd, Puchong, Selangor, Malaysia for supplying the materials used for the preparation of Turkom-Cera specimens.

REFERENCES

1- Andreatta OD Filho, Bottino MA, Nishioka RS, Valandro LF, Leite FPR. Effect of thermocycling on the bond strength of a glass-infiltrated ceramic and a resin luting cement. J Appl Oral Sci. 2003;11(1):61-7.
2- Bakke M, Holm B, Jensen BL, Michler L, Möller E. Unilateral, isometric bite force in 8-68-year-old women and men related to occlusal factors. Scand J Dent Res. 1990;98(2):149-58.
3- Blatz MB, Richter C, Sadan A, Chiche GJ. Critical appraisal. Resin bond to dental ceramics, Part II: high-strength ceramics. J Esthet Restor Dent. 2004;16(5):324-8.
4- Braun S, Bantleon HP, Hnat WP, Freudenthaler JW, Marcotte MR, Johnson BE. A study of bite force, part 1: relationship to various physical characteristics. Angle Orthod. 1995;65(5):367-72.
5- Cehreli MC, Kökät AM, Akga K. CAD/CAM Zirconia vs. slip-cast glass-infiltrated Alumina/Zirconia all-ceramic crowns: 2-year results of a randomized controlled clinical trial. J Appl Oral Sci. 2009;17(1):49-55.
6- Charlon DG, Roberts HW, Tiba A. Measurement of select physical and mechanical properties of 3 machinable ceramic materials. Quintessence Int. 2008;39(7):573-9.
7- Clarke D. Interpenetrating phase composites. J Am Ceram Soc. 1992;75(4):739-59.
8- Conrad HJ, Seong WJ, Pesun JJ. Current ceramic materials and systems with clinical recommendations: a systematic review. J Prostheth Dent. 2007;98(3):389-404.
9- Della Bona A, Borba M, Benetti P, Cecchetti D. Effect of surface treatments on the bond strength of a zirconia-reinforced ceramic to composite resin. Braz Oral Res. 2007;21(1):10-5.
10- Ferrario VF, Sforza C, Zanotti G, Tartaglia GM. Maximal bite forces in healthy young adults as predicted by surface electromyography. J Dent. 2004;32(6):451-7.
11- Fleming GJ, Narayan O. The effect of cement type and mixing on the bi-axial fracture strength of cemented aluminous core porcelain discs. Dent Mater. 2003;19(1):69-76.
12- Fleming GJ, Shelton RM, Marquis PM. The influence of clinically induced variability on the bi-axial fracture strength of aluminous core porcelain discs. J Dent. 1999;27(8):587-94.
13- Gibbs CH, Mahan PE, Mauderli A, Lundeen HC, Walsh EK. Limits of human bite strength. J Prostheth Dent. 1986;56(2):226-9.
14- Giordano RA 2nd, Pelletier L, Campbell S, Pober R. Flexural strength of an infused ceramic, glass ceramic, and feldspathic porcelain. J Prostheth Dent. 1995;73(5):411-8.
15- Haselton DR, Diaz-Arnold AM, Hills SL. Clinical assessment of high-strength all-ceramic crowns. J Prostheth Dent. 2000;83(4):396-401.
16- International Organization for Standardization. ISO 6872:1995, Dental ceramic. Geneva: ISO; 1995.
17- McLean JW, Hughes TH. The reinforcement of dental porcelain with ceramic oxides. Br Dent J. 1965;119(6):251-67.
18- Oilo G. Flexural strength and internal defects of some dental porcelains. Acta Odontol Scand. 1988;46(5):313-22.
19- Okiyama S, Ikebe K, Nokubi T. Association between masticatory performance and maximal occlusal force in young men. J Oral Rehabil. 2003;30(3):278-82.
20- Qualtrough AJ, Piddock V. Dental ceramics: what's new? Dent Update. 2002;29(1):25-33.
21- Rizkalla AS, Jones DW. Mechanical properties of commercial high strength ceramic core materials. Dent Mater. 2004;20(2):207-12.
22- Santos MJMC, Francischone CE, Santos GC Jr, Bresciani E, Romanini JC, Saquito R, et al. Clinical evaluation of two types of ceramic inlays and onlays after 6 months. J Appl Oral Sci. 2004;12(3):213-8.
23- Seghi RR, Daher T, Caputo A. Relative flexural strength of dental restorative ceramics. Dent Mater. 1990;6(3):181-4.
24- Sundh A, Sjögren 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(7):682-8.
25- Taya M, Hayashi S, Kobayashi A, Yoon HS. Toughening of a particulate reinforced ceramic matrix composite by thermal residual stress. J Am Ceram Soc. 1990;73(5):1382-91.
26- Thompson VP, Rekow DE. Dental ceramics and the molar crown testing ground. J Appl Oral Sci. 2004;12:26-36.
27- Tinschert J, Zwez D, Marx R, Anusavice KJ. Structural reliability of alumina-, feldspar-, leucite-, mica- and zirconia-based ceramics. J Dent. 2000;28(7):529-35.
28- Wagner WC, Chu TM. Biaxial flexural strength and indentation fracture toughness of three new dental core ceramics. J Prostheth Dent. 1996;76(2):140-4.
29- Wang L, D’Alpino PHP, Lopes LG, Pereira JC. Mechanical properties of dental restorative materials: relative contribution of laboratory tests. J Appl Oral Sci. 2003;11(3):162-7.
30- Wei GC, Becher PF. Improvements in mechanical properties in SiC by the addition of TiC particles. J Am Ceram Soc. 1984;67(8):571-4.
31- Wen MY, Mueller HJ, Chai J, Wozniak WT. Comparative mechanical property characterization of 3 all-ceramic core materials. Int J Prosthodont. 1999;12(6):534-41.
32- Yilmaz H, Aydin C, Gul BE. Flexural strength and fracture toughness of dental core ceramics. J Prostheth Dent. 2007;98(2):120-8.
33- Zeng K, Odén A, Rowcliffe D. Evaluation of mechanical properties of dental ceramic core materials in combination with porcelains. Int J Prosthodont. 1998;11(2):183-9.
34- Zeng K, Odén A, Rowcliffe D. Flexure tests on dental ceramics. Int J Prosthodont. 1996;9(5):434-9.