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

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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 an 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 materials[1].

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)[8,20,22,26,32]. 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 dentures[12,21,23].

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[17]. 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[14].

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 Fused Alumina, Turkom-Ceramic (M) Sdn. Bhd., Puchong, Selangor, Malaysia), densely sintered aluminum oxide ceramic (Procera), and zirconium oxide ceramic (Procera AllZirkon, Nobel Biocare, Göteborg, Sweden; Lava, 3M ESPE, St. Paul, MN, USA) are popular high-strength ceramic materials that offer favorable esthetic characteristics, mechanical properties and biocompatibility[3,9].

In-Ceram Alumina has a high strength ceramic core fabricated through the slip-casting technique[15,24]. A slurry of densely packed Al_2O_3 (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[5,8,15].

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 by 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 stone 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[2,4,10,13,19]. 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[29]. Because of different compositions and manufacturing techniques, dental ceramics vary in their physical and mechanical properties[6]. One important property is the strength of the materials, and specially the flexural strength, because of the brittle nature of ceramics[18]. 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 dried 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 ISO[16] (1995), all specimens were subsequently grinded 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 ISO[16] (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

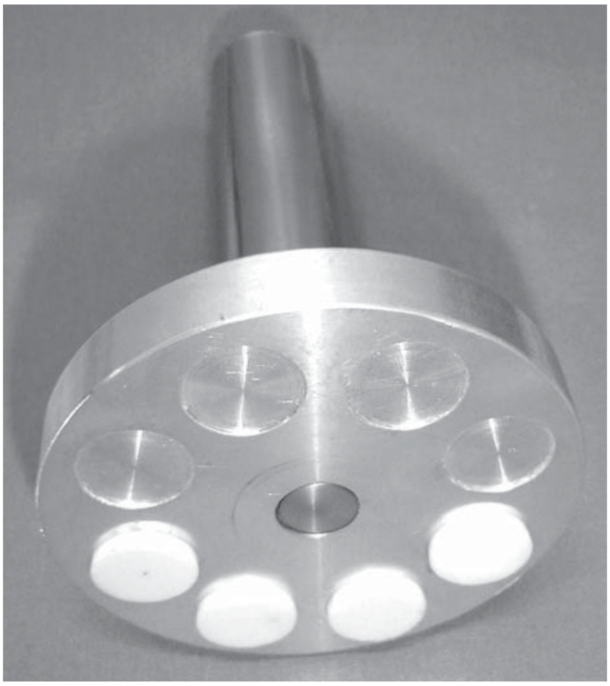

Figure 1- Specimens mounted in the specimen holder

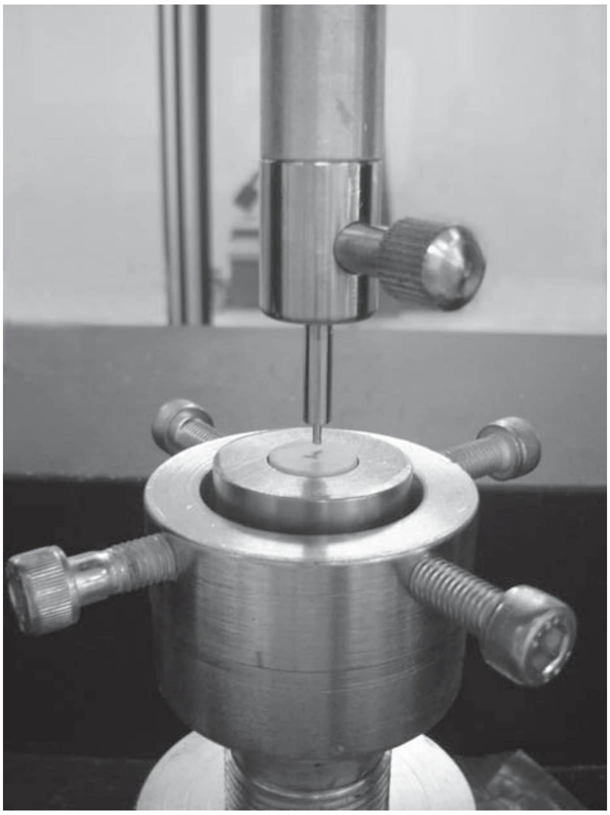

Figure 2- Specimen during testing in the universal testing machine

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	Signi-ficance	95% Confidence Interval	
					Lower Bound	Upper Bound
Tukom-Cera	In -Ceram	159.5*	29.0	.001	78.7	240.2
	Vitadur-N	378.1*	27.8	.000	298.5	457.7
In -Ceram	Tukom-Cera	-159.5*	29.0	.001	-240.2	-78.7
	Vitadur-N	218.6*	10.0	.000	191.4	245.9
Vitadur-N	Tukom-Cera	-378.1*	28.0	.000	-457.7	-298.5
	In –Ceram	-218.6*	10.0	.000	-245.9	-191.4

* Based on observed means, the mean difference is significant at the 0.05 level

distances from each other (120° apart) and 5 mm from the center forming a tripod. These depressions were the sites for the 3.2 mm stainless steel ball bearing supports.

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[16]: Biaxial flexural strength=-0.238 $7P(X-Y)/d^2$; $X=(1+v)\ln(r_2/r_3)^2+[(1-v)/2](r_2/r_3)^2$; $Y=(1+v)[1+\ln(r_1/r_3)2]+(1-v)(r_1/r_3)2$, where P is the total load causing fracture (N), v 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), 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 preset 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 pre-set 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[33]. 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 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[28,31].

According to ISO[16] (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 followings[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).

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