ACTA SCIENTIFIC DENTAL SCIENCES (ISSN: 2581-4893)

Volume 3 Issue 5 May 2019

Research Article

All-Ceramic Restorations of Disilicate Lithium, Alumina and Zirconia Part A: *In-Vitro* Data

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Received: March 14, 2019; **Published:** April 29, 2019

Abstract

All-ceramic restorations are a growing trend in dentistry as they offer better aesthetics and biocompatibility than metal-ceramics. Occasionally different ceramic systems have appeared. The purpose of this study was to review the laboratory studies related to Lithium Disilicate, Zirconia and Alumina ceramics, to record the fracture strength values and the fracture patterns observed during loading.

Lithium Disilicate and Alumina ceramic systems have fracture strength values lower than Zirconia ceramics, but always higher than the normal mastication forces. Thus, Lithium Disilicate and Alumina ceramics may be used in the anterior region, while those of Zirconia could be applied in the molar region.

In summary, it should be mentioned that laboratory models can not accurately reproduce the stomatognathic system. Hence, the results obtained from such studies should be evaluated carefully.

Keywords: Lithium Disilicate; Alumina; Zirconia; Fracture Resistance

Prologue

Dental ceramics are materials with many advantages, such as biocompatibility, aesthetics, less plaque retention, resistance to abrasion and stable color rendering. Initially, their application was limited to the anterior aesthetic zone. Today there is a tendency for use in posterior areas. The chipping of the veneered ceramic or complete detachment of the veneered ceramic (delamination) are still the main complications [1,2]. In recent decades many ceramic materials have been tested in different laboratory studies to check their appropriateness for use in the oral environment. The various laboratory models involve either single crowns or fixed bridges, which are subject to different forces, depending on the protocol of each research group [3]. The objective of this study is the literature review of laboratory studies related to lithium disilicate, zirconia and alumina ceramics to record breaking levels of each material, and observe the fracture pattern during charging.

Material and Method

In this study were reviewed the English-language literature from 2001 to 2017. The inclusion criteria were: 1) studies with laboratory models of Fixed Dental Prostheses (single crowns and bridges of three to four pieces) of Lithium Disilicate, Alumina and Zirconia for anterior or posterior teeth on which a vertical static force was applied without or after *in-vitro* aging, 2) studies of laboratory observation of all ceramic restorations after intraoral function. Studies that are not related to the strength of the material itself, but how this is influenced by the other factors (e.g., type of cement), were not included in this study. The sample of this study consisted of nine laboratory model studies, two of which compared all ceramic restorations made of lithium disilicate, zirconia and alumina, one was related to lithium disilicate restorations and six involved Zirconia restorations (one of which is finite element analysis). Finally, two fractugrafic studies of Zirconia restorations were included, aiming to observe the the fracture pattern after intraoral function.

Results

The fracture thresholds for the three materials appear to be within the scope of normal bite forces. The bite forces correspond to: 98-299N for the incisor area, 147-368N for canines region 245-500N for the region of premolars and 400-981N for the molar region, while people with bruxism exerted forces greater than 1000N. The results are shown in Table 1.

								In-vitro Aging			Fracture Force (mean)		
Authors	**Framework**	**Veneered ceramic**		**Area**	**Restoration Type**	**Number of Restorations (n)**		**Number of cycles**	**Temperature**	**Time**	**Veneered**	**Without Veneer**	**Apllied force**
Tinschert J. *et al.* (2001)	lithium disilicate (IPS Empress 2)	Glass ceramic fluoroapatite*		Posterior	Bridge 3 pieces	10		-	-	-	1400N	1050N	statics
	Alumina (In-Ceram Alumina)	Feldspar porcelain *				10					> 1000N	> 750N	
	Zirconia (DC-Zirkon)	Feldspar porcelain *				10					2000N	2300N	
Takuma Y. *et al.* (2013)	Zirconia (Everest Zirconium Soft)	-		Posterior	Bridge 4 pieces	90		-	-	-	-	575N	statics
MJ Ambre. *et al.* (2013)	zirconia (Abradere Zirconia)	-		Posterior	Bridge 3 pieces	70		5000	5-55^{o}C	60s / cycle	-	1208N	10000 cycles 30-300N f = 1Hz
Oilo M. *et al.* (2014)	Lithium disilicate (IPS e.max Press)	IPS e-max Ceram		anterior	single crowns	10		-	37^{o}C	24h	700N	-	statics
	Alumina (Vita In-Ceram AL for inLab)	Ducera All Ceram				10					750N		
	Zirconia (Starceram Z-Al-Med HD)	IPS e-max Ceram				10					1550N		
López-Suárez C. *et al.* (2015)	Zirconia (Lava All-ceramic System)	Lava Ceram	-	Posterior	Bridge 3 pieces	10	10	-	-	-	1076N	2581N	statics
	Zirconia (Nobel Procera Zirconia)	NobelRondo	-			10	10	-	-		414N	2070N	
Nawa fl eh N. *et al.* (2016)	Lithium disilicate (LD e-max CAD blocks)	E-max Ceram		Posterior	single crowns	20	10	-	-	-	1075N	-	statics
							10	1500000			987N		
						20	10	-			1548N		
							10	1500000			1482N		
						20	10	-			1455N		
							10	1500000			1163N		
Al-Wahad-ni A. *et al.* (2016)	Zirconia (Ceramill ZI)	Stratification, glass ceramic feldspar (Vita Vm9)		Posterior	Single crowns	15		3000	5-55^{o}C	2min / cycle	1200N	-	statics
		Compression, feldspar glass ceramic (Vita Pm9)				15					857N	-	
		Digitization, feldspar glass ceramic (Vita Triluxe forte)				15					638N	-	
Rodrıguez V. *et al.* (2016)	Zirconia (Lava all-ceramic system)	Lava Ceram	-	Posterior	Bridge 3 pieces	10	10	-	-	-	2581N	3287N	statics
	Zirconia (IPS e.max ZirCAD system)	IPS e.max ZirLiner	-			10	10				2074N	2063N	
Rand A. *et al.* (2016)	zirconia *	Ceramic coating *		Posterior	Bridge 4 pieces	6		-	-	-	2009N	-	Static (FEA)
*: No brand name is mentioned													

Table 1

Lithium disilicate

When the material thickness is sufficient (framework thikness 0.8mm), the fracture force usually exceeded 1000N, reaching up to 1548N, according to Noor Nawafleh., *et al*. [4], while this value is considerably reduced in framework thickness of 0,6mm and in restorations without aesthetic veneered ceramic [5]. Survival rates of laboratory models after cyclic charging of 1,500,000 cycles with increasing force intensity, reach up to 100% without fracture of the framework material or chipping of the veneered ceramic [4].

The fracture force of the material is directly related to the thickness of the framework of lithium disilicate, and is statistically significant increased when the thickness is increased from 0,6mm to 0,8mm, while increased thickness to more than 1mm do not enhance the restoration's strength. Having the framework material thickness reduced from 0,8mm to 0,4mm doubles the risk of fracture of the restoration.

The use of the veneered ceramic greatly increases the fracture threshold by over 20%, under the condition of a strong bond between it and the framework material, and all laboratory manufacturing stages of the restoration should be followed properly. Joachim., *et al*. [5] found that no additional reinforcement strength was achieved after using adhesive systems, however Oilo M., *et al*. [6] expressed an opposite point of view. According to them the use of such systems increases in the clinical resistance of lithium disilicate all ceramic restorations and other glass ceramics.

Concerning the fracture pattern, Nawa fl eh., *et al*. [4] said that after applying vertical static bite force on posterior single crowns, fracture was observed throughout the thickness of the material in the force application area, leading ultimately the crown to separation into two pieces: buccal and lingual (30%) or in three pieces buccal, mesiolingual and distolingual (57%) or four pieces mesiobuccal, mesiolingual, distobuccal and distolingual. (13%). Application of occlusal force in rear three-piece bridges caused crack in the position where the force was applied and the crack was extended to the connector, mainly cervical [5], because it is stress accumulation area and in some cases a fracture at the cervical margin was appeared. Oilo M. et al. [6] mentioned that after applying force to anterior single crowns, a framework fracture at the cervical margin extented vertically to all the surfaces of the crowns, was firstly observed. Chipping of the aesthetic veneered ceramic followed at 60% of the cases.

Alumina

In most cases, the fracture force of ceramic with pure alumina core does not exceed 1000N, but some researchers have reported values exceeding 2000N [3]. Their strength is statistically significant reduced in the absence of aesthetic veneered ceramic, with an average of 600N [5]. However, its use does not enhance the restoration to a desired degree for survival in the posterior region in oral simulation environment.The addition of 35% partially stabilized zirconia to the alumina core increases significantly the strength of the ceramic framework, as the fracture force is doubled compared to that of pure alumina, approaching 2000N [5].

The technical complications include cracking or fracture of the ceramic in the force application area extented to connectors in three-piece bridges and fracture of the ceramic framework to the cervical margin of the restoration, while it is likely to observe chipping of the veneered ceramic at 60%.

Zirconia

Of the three materials tested zirconia had the highest fracture resistance, reaching a three times higher value. In most studies the Zirconia fracture force was higher than 900N (usually> 1000N). Exceptions were the works of Siampri., *et al*. [2], Takuma., *et al*. [7], López-Suárez., *et al*. [8] and Al-Wahadni., *et al*. [9] In the latter studies the lower strength values seem to be related exclusively to the design and construction of laboratory models. However, in all studies the fracture thresholds were considered clinically acceptable for people who do not show bruxism. Increased durability of Zirconia models is also mentioned in the review of Ozcan., *et al* [3] ranging from 437 ± 35N to 2333 ± 183N. However, the difference in breaking force in models with or without ceramic coating varies in different studies.

Fracture in experimental models of Zirconia bridges is observed almost exclusively to the nearest connector to the force application area between abutment tooth- pontic or between two pontics. [7,8,10-12], demonstrating that the dimensions of the connector play an important role in resistance to fracture [7,8,10]. In single crowns fracture often starts at the cervical margin, indicating that the cervical margin is the most delicate point of the crown [6]. These results are confirmed by both fracturegraphic studies [13,14]. In contrast, where chipping of the veneered ceramic (partial or full) was observed, the fragments came from the area where force was applied. These standards are also confirmed by fracturegraphic studies [13,14]. A common complication of Zirconia restorations is chipping of the veneered ceramic ending up to complete detachment of the veneered ceramic or framework fracture. The bond between the zirconia framework and the veneered ceramic appears to play the major role. In the work of Al-Wahadni., *et al.* [9] (single crowns) different comparative techniques of ceramic coating are described (Layering, Compression and Digitization), with the classic layering technique giving the highest fracture resistance (Table 1) and mainly chipping of the veneered ceramic was observed. This fracture pattern appeared in two of the three groups examined by researchers (exception was the group of CAD/CAM with complete detachment of the veneered ceramic). Inconsistent results for the fracture pattern resulted from the work of López-Suárez., *et al* [8] (three-unit bridges), where models of Lava CAD/CAM ceramics exhibited chipping of the veneered ceramic, while models of Procera CAD/CAM ceramic mainly showed complete detachment of the veneered ceramic. The fracturegraphic studies Oilo., *et al.* [13] and Pang., *et al.*. [14] confirmed that the chipping of the veneered ceramic is the main reason of failure, with latter saying that fracture of the Zirconia framework was observed more frequently than expected.

Discussion

Lithium disilicate

Lithium disilicate all-ceramic materials have increased flexural strength and resistance to fracture, compared with conventional ceramic materials. The significantly improved mechanical properties, compared to the ceramics used to metal-ceramic restorations, are related to their increased content of crystal phase, which amounts to up to 70%, and their manufacturing techniques (moldable heatpressured-ceramic), favoring the uniform distribution of crystals, while theCAD/CAM technique further enhances their strength [1].

The strength of these restorations is mainly related to the framework thickness which should be ≥0,8mm [4]. Thus, in restorations with sufficient thickness of material, the fracture force can exceed 1500N allowing the survival of the restoration in the oral environment [5], while cyclic loading conditions of 1,500,000 cycles corresponding to 6 years of oral function, survival reaches 100% for posterior single crowns, without any technical complication [4]. Generally, laboratory models in which *in-vitro* aging was applied exhibited lower fracture resistance compared to those where aging was not applied efarmosthike [4-6].

Although the use of aesthetic veneer material to the ceramic lithium disilicate is not necessary to render the desired optical properties, it is observed that this significantly enhances their resistance to fracture. At this point it should be noted that the most decisive role in the mechanical strength of a ceramic material is played by the framework material [6] and the content of crystalline phase.

The technical complications are primarily related to the fracture of the ceramic material through its thickness in the area where the static force is applied, the fracture extension to the connector area of a three-unit bridge and fracture of the framework in the cervical margin. It should be noted that the cervical margin of a restoration is a region of reduced material thickness and weakness, while at the connector area where stresses are accumulated during intraoral function [5,6].

The use of all-ceramic lithium disilicate restorations is proposed for anterior aesthetic zone, while for molar area is considered insecure.

Alumina

These ceramics are considered of a pure strong alumina core reinforced with glass fillers while the CAD/CAM technique seems to enhance their strength. Laboratory results however are not entirely encouraging in terms of fracture resistance since in most cases the fracture force did not exceed 1000N [5,6], making it prohibitive to use them in posterior area. The major complication is the fracture of the ceramic core in the area of the applied force, but also at sites of weakness, such as connectors and cervical margins.

The addition of 35% partially stabilized zirconia in the alumina core appears to double the fracture resistance which is close to 2000N allowing the use of such materials at the molar area [5].

As with the lithium disilicate ceramics restorations of alumina may be placed safely in the anterior area.

Zirconia

Zirconia seems to be the ceramic that can provide satisfactory solutions on both the anterior and posterior area. As is clear from relevant studies, Zirconia ceramic restorations can withstand forces greater than 1000N (many times greater than 2000N). In-vitro aging generally led to lower fracture resistance in relation to cases where there aging was not applied [4,5,8-12]. Quite often, when a veneered ceramic is used to achieve the desired aesthetics chipping of the veneered ceramic or complete detachment of the veneered ceramic is the first appeared complication [6,8,9]. This phenomenon is attributed by most researchers in the weak bond between the zirconia framework and the veneered ceramic, because of the difficulty showed by the zirconia framework during its process to create the bond.

Also, the fact that in fixed bridges the fracture is appeared in the connector area demonstrates the importance of the proper design of the framework. Takuma., *et al*. [7] indicate that in four-unit bridges the increased cevicocclusal height, the increased surface of the connector (connectors of 9mm^2 and 7mm^2 were examined) and the increased ratio of cervicocclusal/ buccalingual dimensions enhance the resistance of the restoration. Adding to these Ambre., *et al*. [10] suggested a 3x3 (mm) connector for the anterior teeth and the premolars and 4x4 (mm) for the molars, as sufficient for three-unit bridges. Thickness of 0,3mm of Zirconia framework was acceptable, with some manufacturers even recommend 0,7mm for reduced complications [10]. Finally, MP Dittmer., *et al*. [15] demonstrated in computer simulation that in 4-unit bridges a maximum of 49 occlusal contacts (according to Thomas) reduce the fractures and the stresses accumulated in the connector area .

Conclusions

The conclusions drawn from the review of laboratory studies are:

- Chipping of the veneered ceramic is still the main complication in all materials tested.
- Lithium Disilicate ceramic restorations and Alumina all-ceramic restorations can be used safely in the anterior area, while their use in the molar area seems to be prohibitive.
- Zirconia is the most resilient ceramic to fracture allowing its use to the molar area but only in bridges tup to four units.
- The results from the laboratory studies should be evaluated carefully, because no laboratory model can accurately simulate the complex conditions of the stomatognathic system.

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