

EVALUATION OF DIFFERENT IN VITRO TESTING METHODS FOR MECHANICAL PROPERTIES OF VENEER CERAMICS

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Abstract

Metal-ceramic and all-ceramic prosthetic restorations in the patient mouth are often damaged by esthetic and functional problems that reduce their success and longevity.

Aim: To evaluate methods for testing mechanical characteristics of dental ceramics through analysis of different testing methods.

Material and methods: Dental ceramic materials are tested with in vivo and in vitro methods for their most important mechanical characteristics: hardness, toughness, flexural strength and abrasion. In vitro testing methods are faster and more efficient, without subjective factors from the patient according to ISO standards. Testing is done with universal testing machines, like Zwick 1445, Universal Testing Machine (Zwick DmbH & Co.KG, Ulm, Germany), Instron 4302 (Instron Corporation, England), MTS Sintech ReNew 1123 or in oral chewing simulators.

Results: According to the testing results, flexure strength is one of the most important characteristic of the dental ceramic to be tested, by the uniaxial and biaxial tests. Uniaxial tests three-point and four-point flexure are not most appropriate because the main stress on the lower side of the tested specimens is tension that causes beginning fractures at the places with superficial flow. Uniaxial results for flexural strength are lower than actual force, while with biaxial test defects and flows on the edges of tested specimens are not directly loaded.

Conclusion: Biaxial flexural method has advantages over uniaxial because of real strength results, but also for simple shape and preparing of the testing specimens.

Key words: dental ceramics, dental crowns, bridges, testing methods, flexural strength.

Introduction

Technological progress in dentistry and the patient's demand for better esthetics, not only in frontal, but in posterior region is the reason for increased use of many different dental ceramic systems. Dental ceramic materials for veneering layer over metal and ceramic core are usually the weakest part of the restorations. Their mechanical properties are responsible for potential failure or success in any restoration [1].

Ceramic response to masticator forces may be elastic or reversible, plastic or irreversible

and or a combination of them [2]. Dental restorations are loaded with three different force types such as axial (tensile/compressive), strain (sliding/rubbing), bending and torsion movement. The average forces in the frontal part of the jaws are 155 N for incisors, 208 N for cuspids, 288 N for bicuspid, while in the posterior region forces rising up to 390 N for the first molar to 800 N for the second molar. Masticator forces vary in different genders, age and muscle configuration [3].

Chipping of the brittle ceramic veneer is the most often problem that occurs during masti-

cation, and ceramic strength is crucial for clinical success [4]. For the patients it is esthetic problem, but for the dentist it is a problem with reduced vertical dimension, reduced masticator efficiency, occlusal disorder with overloading of the teeth and TMJ [5].

Standards for laboratory testing of the ceramic materials were formulated in 1984, and have been changed and upgraded several times since then. EVS-EN ISO 6872: 2008 gives recommended methods for the biological evaluation of dental ceramics [6]. Standards are very important tools in dental studies because they define important parameters that are crucial for good scientific work. They determine methods, preparation of test specimens and test apparatus.

Methods for testing flexural strength define mechanical properties such as strength and fracture resistance of any type of dental ceramic [7, 8]. All-ceramic restorations are very complex, and there is no standard method for their measuring as of yet. Strength data obtained from different testing procedures and specimen shapes are used as indicators of the structural performance of dental ceramic material.

The aim of this paper is to evaluate the test methods for mechanical characteristics of all-ceramic materials through analysis of different testing methods and to discuss about their limits and clinical implications. Testing methods influence greatly in obtained results and they should be well recognized. We investigated only relevant online sources Pub med database, articles and reviews in English language published from 1995–2014.

Materials and methods

Literature data for testing mechanical properties of dental ceramic materials are divided in two groups: testing done in vitro and in vivo conditions. In vivo testing methods are subjective, harder and longer to perform. It is very hard to establish a natural environment like the one present in the mouth, but in vitro testing are done according to standards and are faster and more efficient without the presence of subjective factors like masticator forces and different types of food. However in our paper we investigate different in vitro testing methods and evaluate their procedure and interpretation

of the results. In vitro testing methods are divided in two big groups: uniaxial and biaxial bending tests according to the specimen shapes and testing procedure.

Uniaxial bending tests for flexure strength

Three – point and four – point bending tests are standard tests for evaluating dental ceramic materials. Specimen shape in both tests is like a beam, supported at both ends and loaded until it fractures.

Three – point bending test applies pressure in the central part of the beam and produce tensile stress on the lower side of the specimen. There is 12–15 mm distance between the supports, loading surfaces have 1.6 mm diameter and the loading chisel is moving with 0.5–1mm/min so the fracture occurs within 5–15 seconds (Figure 1). The initiate crack and fracture usually starts from the sites with any defects and flows in the material. There is formula for calculating the flexure strength where length of the span, width and thickness of the specimen is measured.

$$\sigma = 3 FL / 2 bd^2, \text{ where}$$

σ is modulus of rupture or Flexural strength (MPa); F is force (N); L is length of the span (mm); d is thickness (mm) and b is width of the specimen (mm).

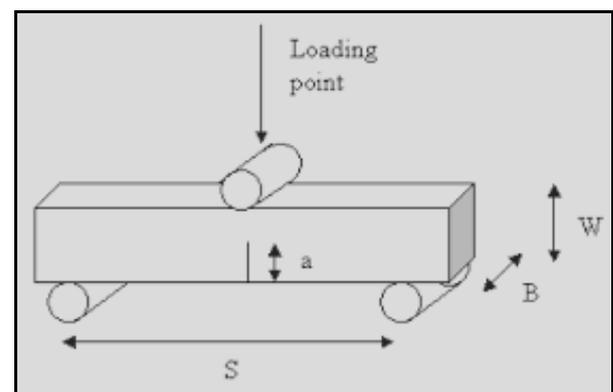


Figure 1 – Three – point bending test

This test was used in many papers due to the relatively simple test design, easy preparation and simple form of the testing specimens.

Four – point bending test is usually used for testing of one and two layered struc-

tures like glass-ceramic veneer over metal and ceramic core. Specimen shape is rectangular and it lies on the supports with 21 mm distance (Figure 2). Four – point bending test applies main pressure over larger specimen area because the beam is loaded with not one, but two chisel until fracture. This test is similar to the previous one, but the stress distribution is even. The calculating formula for flexure strength is

$$\sigma = 3 F (L-l) / 2 wh^2, \text{ where}$$

σ is modulus of rupture; F is force (N); L is span length (mm); l is distance between loading chisels and h is height of the beam.

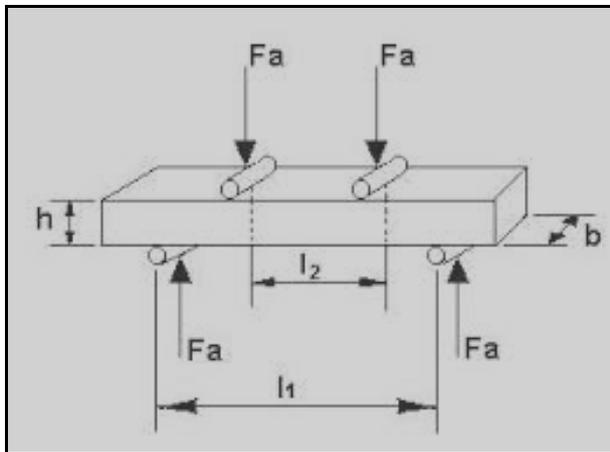


Figure 2 – Four – point bending test

Biaxial bending test for flexure strength

This test was designed and introduced to the standard testing procedures mainly because uniaxial test were primarily designed for engineering materials with large samples where the shape and size influenced the test results. Testing designs vary and today there are three different test methods: ball – on – ring, ring – on – ring and piston – on – three – ball test. In 1991 the piston – on – three – ball was recognized as standard test (ASTM F 394 in ISO-6872) for biaxial flexure strength of ceramic materials and we considered only papers with this test.

In piston – on – three – ball test specimens have disc form with diameter 12–16 mm, height 1, 2–2 mm and they are placed in the mounting jig over three steel balls (Figure 3). The balls are positioned at equal distance from

each other and 5 mm from the center forming tripod. Piston has cylindrical shape with 1, 6 mm diameter and it is loading pressure in the centre of the disc with crosshead speed of 1mm/min. The force is applied until the specimen fracture and the failure stress is calculating with the formula

$$\sigma = - 0.238 7P (X-Y) / d, \text{ where}$$

$$X = (1+\nu) \ln (r_2/r_3) + [(1-\nu)/2](r_2/r_3)^2$$

σ is the modulus of rupture (MPa); P is total loading fracture (N); ν is Poisson's ratio (0. 25 for ceramic materials); r_1 is radius of the supporting circle (5. 0 mm); r_2 is radius of the loaded area (0,8 mm), r_3 is the radius of the specimen and d is the thickness of the specimen at the origin of the fracture (mm).

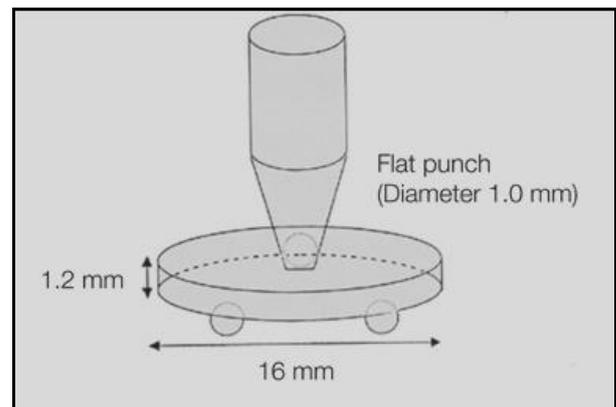


Figure 3 – Piston – on – three – ball test

Loading pressure is more symmetrical and the discs are loaded on both sides, while maximal flexure appears in the central and not at the peripheral edges of the sample.

Oral chewing simulators

Several papers presented testing of the dental ceramic materials in the oral chewing simulators. Simulators have several testing chambers for simultaneously testing of specimens with flat, but also specimens with anatomical shapes – crowns and bridges. Loading stress is applied as axial force vertically on the occlusal surface during cyclic dynamic movement according to the masticatory process (Figure 4). Computer software precisely monitors and con-

trols the loading process with specific requirements: 0–50 N dynamic or static loading force; 10 N force impulse; 39–41 mm/sec horizontal and vertical movement speed; 1.58–1.62 Hz loading frequencies; 390–420 m/sec time contact and minimal 4.8–5.2 maximal 54–56 °C.

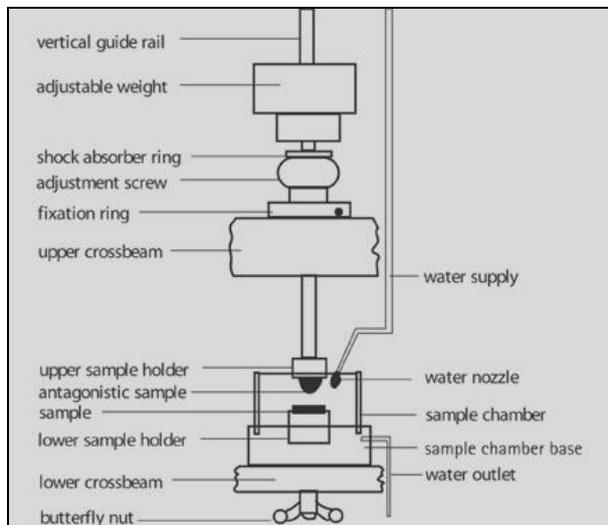


Figure 4 – Chewing simulator

Antagonist material in these simulators is Steatite ceramic ball (Höchst Ceramtec, Wunsiedel, Germany) with diameter 6 mm, which presents the dimension of the functional masticator cusps, but very often antagonist are natural teeth.

Results

Most of the papers showed very high variability in presented testing methods and results. Uniaxial and biaxial bending tests were used for testing of very different dental ceramic materials with different composition and manufacturers. Some papers even used several testing methods trying to compare and present the best methods and results. Statistical data showed high variability between the results for one material tested with three-point flexural strength, four point flexural strength and biaxial flexure strength.

For all of the tested specimens strength values for three-point test were significantly higher than those for four-point tests. Flexural strength results for four-point tests were lower in all of the papers, due to superficial cracks between loading clips, opposite of the smaller loading surface in three-point tests.

There were statistical significant differences between uniaxial and biaxial flexure strength

test also. Strength data for uniaxial tests showed lower values than real strength of the materials, while results for biaxial test are correct and correlated with the real strength of the materials.

In most of the papers results of all three testing methods were correlated. The four – point flexure test had highest difference between ceramic materials in several papers.

Discussion

Continuous loading of the prosthetic restorations during masticator process in the oral media with the influence of the saliva pH and temperature are damaging the veneering materials. Chipping is reported to be the most frequent failure in all-ceramic restorations after a service time of 3–5 years. In vitro testing of the mechanical properties of dental ceramic materials can provide us good information for their clinical performance.

Dental ceramic is brittle material with high elastic module and is more sensitive to tensile stresses produced during mastication. Ceramic strength is considered as a tensile strength, because it is more important than compressive strength. Tensile strength test used to evaluate most materials are not suitable for testing of dental ceramic, and that is why in laboratory practice were established different test methods in order to evaluate ceramic strength.

All testing procedures are done on universal testing machines Zwick 1445 Universal Testing Machine (Zwick DmbH & Co.KG, Ulm, Germany), Instron 4302 (Instron Corporation, England), MTS Sintech ReNew 1123 with certain modification and received strength values are result of simple geometrical shapes of tested specimens that don't correspond with intraoral clinical situations.

Uniaxial strength tests have specimens like beams or bars, they are difficult to prepare and loaded only in one point. Final testing results in these methods depend on shape, flatness and polished surfaces. Three-point test is used very often because of its simplicity but improper shape and surface flows on the specimens can change results for 10 %. Good polishing can reduce the effect of surface flows, and rounding the edges can improve test repro-

ducibility for 20–30%. In this test only small thin layer on the lower surface is exposed to maximum tensile stress and it results in higher strength values than with other testing methods.

Biaxial strength tests have several advantages compared to uniaxial because of the easier preparation of the test specimens discs instead of bars and central loading of the force on the discs with possibility to test greater surface [9], [10]. This test design has higher values compared to three-point test [11] and it allows testing of smaller specimens where flow distribution is similar to clinical restorations [12]. Specimen shape more similar to the restorations is without consequences from the edge fracture, because they are not directly loaded [13]. Piston – on – three – ball biaxial test method introduces high stress gradient on the specimen tensile surface and central loading area is exposed to maximum tensile stresses [14]. Piston – on – three – ball test also recommends unifying of the field pressure with thin plastic foil, which means certain limits for statistical analysis [15].

Oral simulators can imitate the forces and dynamic processes of human teeth and precisely reproduce the damages of the ceramic materials in the mouth. Dental crowns and bridges can be tested fast and simple [16, 17]. Using different types of abutment give different result but mobile abutments provides higher strength values than immobile [18]. Dynamic loading has lower strength than static and water and temperature also reduce strength values for the materials [19].

Conclusion

Within the limitation of the study we concluded that biaxial test methods are simple and easy to perform, their results are more precise and punctual compared to uniaxial tests. Uniaxial tests provide higher result that didn't respond to the real strength values of the ceramic materials and are not recommended for use.

Oral chewing simulators are capable to provide very precise result and are presented like best methods for testing of the flexure strength of different dental ceramic materials. However they are very expensive, only few laboratories

in research centers have them and are used quite rarely compared with other testing methods.

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Резиме

ЕВАЛУАЦИЈА НА ТЕСТОВИТЕ IN VITRO ЗА ОДРЕДУВАЊЕ НА МЕХАНИЧКИТЕ ОСОБИНИ НА ПОРЦЕЛАНСКИТЕ МАСИ ЗА ФАСЕТИРАЊЕ

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Метално-керамичките и целосно керамичките протетички реставрации во устата на пациентите честопати се оштетуваат и предизвикуваат естетски и функционални проблеми со кои се намалува нивниот успех и долготрајност.

Цел на трудот: Да се проценат методите за евалуација на механичките особини на кера-

мичките маси преку анализа на различни тестирачки методи.

Материјал и метод на работа: Методите за мерење на механичката отпорност на денталната керамика се изведени in vitro и in vivo и со нив се испитувани најважните особини на керамичките материјали: цврстина, тврдина, отпорност на свиткување и абразија. Со методите in vitro денталните керамички маси се испитуваат побрзо и поефикасно, без субјективни фактори од страна на пациентот според ISO-стандарди. Тестирањата се изведуваат на универзални тестирачки машини Zwick 1445 Universal Testing Machine (Zwick DmbH & Co.KG, Ulm, Germany), Instron 4302 (Instron Corporation, England), MTS Sintech ReNew 1123 или во орални симулатори за цвакање.

Резултати: Според добиените резултати, силата на свиткување како најважна особина на крутата керамика се мери со униаксијални и биаксијални тестови. Униаксијалните тестови со три и четири точки не се најсоодветни затоа што главниот стрес на долната површина на испитуваниот примерок е тензија, која предизвикува почетна пукнатина на местата со површинска грешка. Податоците за силата добиени со униаксијалните тестови се пониски од висинската сила на материјалот, а кај биаксијалните тестови тоа не е случај затоа што дефектите и грешките што се јавуваат на рабовите на испитуваните примероци не се директно оптоварени.

Заклучок: Биаксијалната тестирачка метода има предност во однос на униаксијалната поради поточните резултати за силата, но и поради поедноставната форма и подготовка на примероците за испитување.

Клучни зборови: дентална керамика, коронки, мостови, тестирачки методи, сила на свиткување.