

Evaluation of the Three-year Experience with All-ceramic Crowns with Polycrystalline Ceramic Cores

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Abstract: The objective of the study was to evaluate the clinical outcomes of all-ceramic crowns three years after placement of the restoration in the oral cavity. The aim of the present clinical study were surveyed the Procera[®], Cercon[®] and LAVA[™] systems. In total, 121 crowns were followed in 33 patients (7 men and 26 women) with an average age of 53.5 years. The eighty crowns were placed in anterior and forty one crowns in posterior teeth. The crowns were fabricated in two dental laboratories and delivered in two private dental practices. The clinical trial was conducted according to American Dental Association guidelines. The patients were requested to provide their consent to the regular clinical examination including radiographic and photographic records. A total of 102 crowns were made of zirconium oxide ceramic cores – 58 Cercon[®]; 43 LAVA[™], while 19 crowns were made of aluminum oxide cores Procera[®]. The veneering ceramic LAVA[™] Ceram was used. The success rate was analyzed using Kaplan-Meier statistics and, in our case, the overall three-year success rate reached 96.7%. All-ceramic crowns with polycrystalline ceramic cores have low susceptibility to fracture, in this study just 3.3%.

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Introduction

The worldwide trend in recent years is to accentuate the excellent aesthetics and biological inertness of materials used for crown restorations (Subbarao, 1981; Piconi and Maccauro, 1999).

Patients have become increasingly interested and aware of state-of-the-art technologies and enthusiasm for all-ceramic crowns has risen accordingly. Previously used silicate ceramic crowns were satisfactory in aesthetic and biological outcomes, but from the clinician's view, their indications were limited due to insufficient mechanical strength. Feldspathic and glass ceramics failed to comply with the strength requirements of ISO 22674 (Flexural strength, <50 MPa).

The introduction of polycrystalline ceramics, where the core is reinforced with aluminum oxide or yttrium-stabilized zirconia (3Y-TZP-yttrium cation-doped tetragonal zirconia polycrystals) brought new products to clinical dentistry that meet the most demanding contemporary clinical requirements (Tyszbłat Sadoun, 2001).

Zirconia, also known as zirconium dioxide, is found in three crystalline phases. It is known to crystallize in the monocrystalline (monoclinic) system at temperatures below 1,170 °C. In temperatures ranging from 1,170 to 2,370 °C, the zirconia forms a tetragonal structure (significantly higher flexural strength than monocrystalline form), while it crystallizes in the cubic form at temperatures above 2,370 °C (Subbarao, 1981). Transformation from a tetragonal to the monocrystalline structure is accompanied by a dramatic expansion of up to 4.5%, and therefore this form of zirconium cannot be used in dentistry. This transformation is reversible and occurs during the cooling process at temperatures of 950 °C and below (Heuer et al., 1986).

Pure zirconia can be stabilized from reverting to monocrystalline form by adding the following oxides: CaO, MgO, Y₂O₃ or CeO₂. The resulting crystal has a tetragonal structure even at room temperature (Sato et al., 1985; Deville et al., 2006). This material has a good resistance to bending and its properties change little with age (Sato and Shimada, 1984; Denry and Kelly, 2008). Results showed that the CAD/CAM-machined surfaces initially exhibited superior hydrothermal degradation resistance, but deteriorated at a faster rate upon prolonged autoclave treatment compared with ground and grit-blasted surfaces (Kim et al., 2010).

The following three types of zirconia are used in dental medicine (Raigrodski, 2006):

1. *3Y-TZP (yttrium cation-doped tetragonal zirconia polycrystals)* is a zirconia containing 3 mol % Y₂O₃, which serves as a stabilizer (e.g. Cercon[®], Dentsply Ceramco, USA). It is fabricated from pre-sintered green phase blocks and subsequently sintered at 1,350 to 1,550 °C. It has fine 0.2–0.5 μm grains and post sintered bending strength of 800 to 1,000 MPa.

2. *Glass-infiltrated, alumina-toughened zirconia (ZTA – zirconia-toughened alumina)* is a type classified as bioceramics. In-Ceram® Zirconia® (Vita, Vident™, Brea, USA) is a representative of this group. Initial sintering of the slip cast proceeds for 2 hours at 1,100 °C. The glass phase (Lanthanum) constitutes approximately 23% of the final product. The combination of both these oxides is accompanied by certain microporosity (8–11%) which is higher than the porosity of the densely sintered form of zirconia. The grain size is 2 to 6 µm.

3. The last type is *Mg-PSZ, magnesia partially stabilized zirconia*. This type is not widely used in biomedicine because of a larger grain size (30 to 60 µm) and associated porosity. The quantity of MgO ranges between 8 to 10 mol %. It is produced at high sintering temperatures (1,680 to 1,800 °C). Denzir-M® (Dentronic AB, Sweden) is an example of these materials.

In the present clinical study, the Procera®, Cercon® and LAVA™ systems were surveyed. All these systems have been described in detail repeatedly in the scientific literature (Malament and Socransky, 1999; Piconi and Maccauro, 1999). To date sufficient data is lacking on changes in the strength that occur during aging of the material. Given the flexural strength values of yttrium-stabilized zirconia, the manufacturers anticipate that the materials will comply with the flexural strength requirements of ISO 6872 even after a decrease in strength (Ryge and Cvar, 1971; Chong et al., 2002). The zirconia cores are supplied in colour and therefore have a good balance between translucency and opacity, which means that the core is not excessively transparent despite transmitting light, yet manages to mask dark coloured substrates. It is therefore not necessary to use an opaquer to hide discolourations of prepared teeth or metallic implant components. A great advantage is that fabrication of the zirconia core using the CAD/CAM technology enables shaping the core in such a way that a layer of uniform veneering ceramic can be created throughout, substantially reducing the risk of fracture (chipping) of the veneering porcelain.

The resistance of the veneering materials in cores from polycrystalline ceramics is still under discussion for all-ceramic systems.

Material and Methods

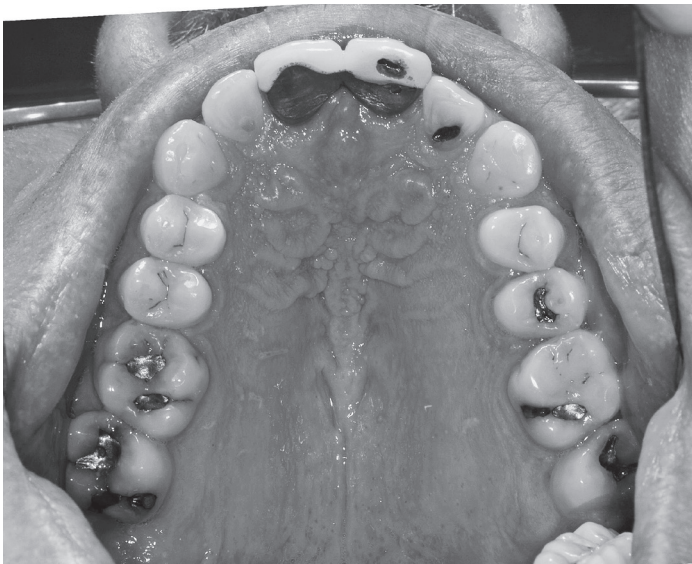
The patient population consisted of 33 subjects (26 women and 7 men) with an average age of 53.5 years, in whom 121 crowns were luted (Table 1).

The treatment procedure

Prior to the preparation of the tooth for an all-ceramic crown, an impression was made using an alginate impression material (Tropicalgin, Zhermack®, Italy) for provisional crowns fabricated by swaging (Protemp II, 3M Espe, USA, Luxatemp, DMG, Germany). The two independent operators performed the treatment. They were calibrated with regard to preparational guidelines (Figures 1 and 2).

Table 1 – Distribution of crowns among the individual teeth

Tooth/location	Maxilla	Mandible	Total
Central incisor	42	10	52
Lateral incisor	6	6	12
Canine	8	8	16
First premolar	6	5	11
Second premolar	5	4	9
First molar	6	6	12
Second molar	4	5	9

*Figure 1 – Patient before treatment from frontal view.**Figure 2 – Patient before therapy from palatal view.*

Tooth preparation was carried out under local anaesthesia to create a circumferential chamfer margin using rotary instrumentation with a medium grit diamond bur. The width of the chamfer ranged from 0.3 to 1.2 mm. Crown preparations were made which was at least 10 to 20 degrees total occlusal convergence (Goodacre et al., 2001), with cusp angle no greater than 120 to 140° degrees, and reduction of the occlusal surface 1.5 to 2 mm according to the individual situation. When preparing posterior teeth, a supragingival preparation was used to facilitate the impression and subsequent inspections. In anterior teeth, subgingival or equigingival preparation was used in the visible part of the dentition on the facial aspect and partially on the proximal surface, while supragingival preparation was used to create the marginal seal on the palatal aspect.

Impressions were made using addition type silicone impression material (Express™ XT Penta™ H, 3M Espe and Express™ XT Regular Body cream, 3M Espe, USA). Retraction cord was used according to the gingival phenotype (#00, #0, #1, UltraPack, Ultradent, Germany) and impregnated in a haemostatic solution (Viscous Coagulative Hemostatik, Ultradent, Germany).



Figure 3 – All-ceramic crowns before insertion.



Figure 4 – All-ceramic crowns (all upper incisors) in situ.

Intermaxillary relationships were registered using wax. During the same visit, tooth abutments of the prepared teeth were always restored with provisional crowns, which were checked for marginal fit. After making an impression of the prepared teeth, a cast was produced which was scanned for all cases.

Initially the received crown cores were assessed for fit and adapted to the prepared tooth abutment. During continuous cooperation with the dental laboratory, the entire crown was inspected in the bisque state. After the high-precision articulation and inspection of the marginal seal, contact points, fitting of the crown and overall aesthetics, the crown was sent to the laboratory for glazing and finishing (Figure 3).

The final luting of the crown was achieved with a self adhesive, resin cement or glass-ionomer cement (Fuji Plus, GC Corp., Japan, or RelyX Luting Plus Cement, 3M Espe, USA). As these are non-etchable ceramics, their superficial internal microscopic surface treatment ensures reasonable cement adhesion in clinical terms (Figure 4).

Clinical trial

A total of 102 crowns were made of zirconium oxide ceramic cores (58 Cercon[®], Dentsply Ceramco, USA and 43 LAVA[™], 3M Espe, USA), while 19 crowns were made of aluminum oxide cores (Procera[®], Nobel Biocare, Sweden). The veneering ceramic LAVA[™] Ceram (3M Espe, USA) was used.

The clinical trial was conducted according to ADA recommendations (Ryge and Cvar, 1971). Patients were requested to provide consent to the clinical examination and regular follow ups, including radiographic evaluation and photographic records, by means of the informed consent form in accordance with the Declaration of Helsinki. The success rate was evaluated using Kaplan-Meier statistics (Kaplan and Meier, 1958).

In total, we evaluated 121 crowns from 33 patients:

Crowns with Zirconia cores (8 pieces) had a reduced core thickness to 0.3 mm (vital teeth in the anterior region). All other crowns had core thickness 0.5 in the anterior region and 0.9–1.2 in posterior part of the jaw.

Crowns (102 single units) were luted to vital teeth and 19 crowns were cemented to endodontically treated teeth.

The endodontic treatment was done by vertical and lateral condensation, using the sealant (AH plus, Dentsply DeTrey, USA) and the gutta percha points (Guttapercha points-VDW GmbH, Germany).

Structurally compromised teeth were restored with FRC posts (LUXA Post, DMG, Germany), as a core material the core composite was used (LUXA Core Z, DMG, Germany). The cast Co-Cr post and cores were secured in posterior teeth (Oraliu Ceramic, Safina, Czech Republic).

The natural antagonist teeth had 61 crowns, opposed ceramic crowns were in 48 cases and resin crowns as antagonists were presented in 12 units.

For evaluation, we created a special questionnaire according to ADA criteria (Table 2). All patients were examined 2 to 3 weeks after the cementing of the crowns. Examination of the margin quality and recurrent caries was performed using a dental probe (CP 2, EXS 96, HuFriedy, Netherlands).

Table 2 – Evaluation of the individual parameters of the crowns according to ADA criteria

Evaluation/parameter	α	β	γ	δ
Evaluation of the gingiva buccal and lingual	optimal condition of the gingiva	visible inflammatory changes	contact bleeding	
Condition of the restoration	intact	visible fissure upon illumination	fracture of the prosthetic work chipping	crown completely missing
Secondary caries	no visible caries on the margin of the prosthetic work	visible decay on the margin of the prosthetic work		
Precision of the marginal fit	the work is well fitted on the prepared portion of the tooth. The sharp-tipped probe is not discontinuous in the margin	the probe is discontinuous in the margin. The fissure, in which the probe is caught, is not visible	a fissure between the margin of the work and tooth, the enamel margin is exposed	a marked fissure at the margin, the dentin or bond is exposed
Assessment of the colour of the restoration buccal and lingual	no discolouration is visible	mild discolouration, which disappears after polishing	a visible stain, cannot be removed by polishing	noticeable colour stains
Comparison of the colour on the buccal surface with the tooth substance	very good colour shade, the work perfectly matches the colour of the dentition	a mild difference in the colour, shade, or transparency	a noticeable difference in colour as compared to the surrounding	marked colour differences

Results

According to ADA recommendations, evaluation was conducted of the vestibular and, oral margins of the crown, the condition of the gingiva in the vestibular and palatal aspects, the condition of the entire restoration, the incidence of secondary caries, the precision of marginal adaptation, and a comparison of colour with the

surrounding teeth and contact points. The evaluation was made by visual inspection using a mirror, a sharp-tipped probe and a radiographic image. All results are indicated as percentage rates (Tables 3–5).

The optimal condition of the gingiva without any inflammatory changes (redness, bleeding, swelling) was found on the buccal surface in 79% and on the lingual surface in 85% of cases. Visible inflammatory changes were seen after 3 years on the buccal surface in 19% of cases, but changes were also present on natural teeth; their presence was not linked to the crowns. On the lingual surface, visible changes were found in 14% of cases. Contact bleeding was found in 2% of cases on the buccal surface and in 1% of cases on the lingual surface.

Table 3 – Evaluation of the marginal fit of the crown

Location of the marginal fit with respect to the gingiva	Supragingival	Equigingival	Subgingival
Buccal	31%	13%	56%
Lingual	69%	24%	75%

Table 4 – Evaluation of the individual crown parameters (%)

Evaluation/parameter	Buccal	α	β	γ	δ
	Lingual				
Evaluation of the gingiva	buccal	79	19	2	0
	lingual	85	14	1	0
Condition of the restoration		95.87	1.6	2.48	0
Secondary caries		100	0	0	0
Precision of the marginal fit		95	4.96	0	0
Assessment of the colour of the restoration	buccal	95	4.9	0	0
	lingual	95	4.9	0	0
Comparison of the colour on the vestibular side with the tooth substance		96.7	3.3	0	0

Table 5 – Evaluation of the gingival condition around the marginal fit (%)

Surface/gingival condition	Optimal	Visible inflammatory changes	Contact bleeding
Buccal	79	19	2
Lingual	85	14	1

Although patients unable to maintain acceptable oral hygiene were not enrolled in the study, gingival inflammation could not be eliminated in all patients.

The condition of the restoration was evaluated at 4 levels as follows: α – intact, β – a fissure visible upon illumination or chipping of the ceramics not requiring replacement of the crown, γ – fracture of the restoration requiring replacement (chipping or fissure requiring replacement of the crown) and δ – loss of the crown.

According to Malament and Socransky (1999), the crown was considered to have failed if the aesthetics or function of the crown was damaged such that it had to be removed and replaced.

According to the Kaplan-Meier statistics (Kaplan and Meier, 1958), the success rate of the 121 crowns was 96.7%. No dental caries was found in the cervical margins of the crowns.

Precision of the marginal seal was satisfactory in 95% of cases, only in 6 crowns the probing engaged a discrepancy, but an opening was not visible. These were crowns with subgingivally located margin. Retention was fully satisfactory in all crowns.

From 102 crowns restoring vital teeth, only 6 teeth showed post cementation sensitivity. The afflicted teeth were frequently impregnated with amine fluoride product (ELMEX gelee, GABA International, GABA GmbH, Germany) which resulted in reduced sensitivity. The sensitivity was caused by the root surface interacting with fruits acids and carbonated beverages. Over the span of three years, we treated the root canals of the first maxillary premolar in one case due to acute pulpitis 12 months after the crown cementation. This premolar



Figure 5 – Chipping of left upper central incisor.

was treated by composite resin restorations in the past. Radiographic evaluation revealed a periapical lesion in the second maxillary premolar, which was also treated endodontically (gutta percha with vertical condensation). In these cases, we performed trephination was performed through the crowns and after endodontic treatment the access was restored with a composite resin material. Both crowns are still present in the patients' mouths. In five crowns, the chipping of veneering ceramics was observed. Two of these were made smooth, polished and are remaining well in function. Both cases involved central upper incisors. Three crowns were fabricated again as new crowns, of which 2 had chipped veneering ceramics (Figure 5) and one also had a fractured zirconia core (Cercon®, Dentsply Ceramco, USA). These crowns were cemented to a maxillary lateral incisor, maxillary canine, and first maxillary premolar. Chipping of the ceramics (including the core fracture) required replacement which occurred 8 weeks after the cementation. All failed crowns had a zirconia core (Cercon®, Dentsply Ceramco, USA) and were cemented with resin reinforced glass ionomer cement (Rely X Luting cement, 3M Espe, USA). This failure occurred in a patient with bruxism and an increased attrition of the teeth before the treatment.

Discussion

In all-ceramic crowns, subgingival margin placement was predominantly made on the facial surfaces of maxillary central and lateral incisors and canines; and also in the maxillary premolars at patients' request (Fradeani et al., 2005). Where possible for aesthetic reasons, i.e. when the smiling line did not expose the gingiva, it was preferred to place the margin equigingivally also on the buccal surfaces. In posterior teeth, subgingival preparation was always preferred, on both the buccal and lingual surfaces. The lower incidence on the lingual surface is probably related to the supragingival placement of the crown margin. The subgingival marginal fit was not satisfactory in 5% of cases, when the probe was discontinuous in the margin of the crown. The subjects were always informed the about this procedure, and explained the advantages whereby they consented to this type of preparation. Visiting the dental hygienist, the patients' hygiene is usually improved, but not all patients were able to keep optimal hygiene level.

In 95% of cases, no disparity was found; the colour and brightness matched that of the adjacent teeth.

Discolouration was found in only in 5% of cases, i.e. in 6 crowns. 4 crowns were discoloured due to strong smoking habit; 2 crowns were discoloured due a strong black tea drinking habit. The discolourations were removed by diamond paste polishing.

In 96.7% of cases, a very good colour match was made; the restoration perfectly matched the neighbouring teeth or crowns. A fine difference in the colour was found only in 4 crowns, where the colour did not fully harmonize with the neighbouring teeth due to previous colour requests of a patient.

Following the literature search, many papers refer to the chipping risk. The reasons of chipping cited are different thermal coefficient of expansion between the core and the veneering ceramics. Some studies demonstrate the chipping risk on the average 3–4% per year (Raigrodski, 2006; Tinschert et al., 2008). The failure of the crown due to chipping is sometimes seen in 8–25% after 24–38 months of use. Slow cooling rate influence chipping risk (Coelho et al., 2009).

Pjetursson and colleagues (2007) referred the survival rates at 5 years of anterior all-ceramic crowns (based on the systematic review) comparable to those seen for metal ceramic crowns. When used for posterior teeth, the survival rates at 5 years of polycrystalline core crowns were 94.9%. These rates were again comparable to those seen for metal ceramic crowns. Furthermore, lower survival rates (90.4% and 84.4%) were obtained for InCeram[®] Zirconia[®] and glass-ceramic crowns. As for fixed partial dental prostheses the same authors (Sailer et al., 2007) referred to the polycrystalline ceramics primarily biological and technical complications prior to framework fracture.

Noting where the development of veneering ceramic must be focused, the results produced from this study correlated with perfect fit CAD/CAM made cores. Therefore CAD/CAM technology can improve inadequate shape of the prepared abutment tooth with variable shape and size of the core, which results in an even thickness of veneering porcelain.

Clinical outcomes seem to be very favourable so far. Interestingly a ceramic chipping (failure of the work) requiring crown replacement occurred in 3 crowns with zirconium oxide cores in a patient with increased wear of the teeth (bruxism).

We instructed the patients on regular check-ups and requested their consent to additional clinical and radiographic check-ups and photographic documentation.

The core thickness was in this case 0.85–1.2 mm and we do not take in that the thickness was the main failure reason. One maxillary premolar core failure (Cercon[®], Dentsply Ceramco, USA) was observed in the case of patient's bruxism. We suppose the core was some involved in the delivery day. Microcracks have been present in the day of insertion.

Unlike the previous systems (Raigrodski, 2006), all-ceramic crowns were indicated for treatment in sensitive and abraded teeth. For successful long-term treatment with all-ceramic restorations patients were enrolled where the periodontium was sound and the caries rate is low – these are a few of the requirements. Our study confirmed that bruxism can be caused chipping and bruxism guard must be used.

The objective for this care is often to treat deficiencies of the enamel or dentin, to restore the loss of hard dental tissue, compromised aesthetics, mastication and sometimes to correct the occlusal plane, or in other words to reconstruct impaired interarch relationships. Another important objective is to avoid further loss of dental hard tissues.

It is a major benefit that the extent of preparation can be adjusted to the needs of the given tooth. It is a goal to preserve as much healthy dental tissue as possible for the longest possible time.

The extent of the crown preparation can be modified in accordance to need from an extension of a porcelain veneer to a crown covering 2/3 or 3/4 of the tooth. However, we should not forget about various types of adhesive luting when using different ceramic types.

For these non-etchable polycrystalline ceramics, some authors recommend using composite resin luting materials, such as Multilink Automix (Ivoclar Vivadent, USA), containing a self-etching primer and bond as a dual cured adhesive. Metal Zirconia Primer (Ivoclar Vivadent, USA) can also be used, which mediates chemical bonding to a non-etchable surface through yttrium-stabilized zirconium oxide. Although some authors report that Multilink Automix has a higher bond strength compared to the materials used in this study such as RelyX Unicem (3M Espe, USA), no adhesion failure of crowns were recorded in this study.

Conclusion

Within limits of this study, all-ceramic crowns with polycrystalline ceramic cores have low susceptibility to fracture in medium term (in this study just 3.3%). Additional follow up time is essential to review the appropriate influence on material aging and longevity of all-ceramic crowns.

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