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Review Article

Primero: Six Years Performance Cognitive Production of Crowns and Bridges

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Abstract

As chipping of porcelain is a common complication in veneered zirconia restorations, a new CAD/CAM fabrication method (Primero®, Cyrtina Dental Group B.V., Zwaag-NL) is proposed for bi-layered restorations using an anatomic substructure of zirconia and a leucite-strengthened porcelain. The resulting restorations were subjected to long-term laboratory fatigue tests of 3-unit bridges and an ongoing 6 year clinical investigation with crowns and bridges and 150 patients. The bi-layered restorations were designed with an dentin-enamel boundary (DEB) that corresponded with the original natural element. The design of the localized thickness of the porcelain layer thus provided the natural color and color gradients found in natural teeth. The high flexibility in the variation in design parameters of the porcelain layer enables a cognitive production approach. The fabrication starts by milling and sintering the zirconia substructure, which is then placed in a refractory block, in which the negative underside of the restoration is milled. The porcelain, in slurry form, is then applied, compacted by centrifuging and the upperside milled and fired. Pressed and hydrostatically compacted zirconia blocks were milled in the green form to enable sharp marginal edges. The zirconia blocks are produced in 16 true cervix colors. The monocolored translucent porcelain has a biphasic matrix containing leucite crystals acting as dispersion hardener and crackstopper. The long term laboratory fatigue tests resulted in major chipping with several porcelains and none with the Primero restorations. In the controlled clinical study period of six years no chipping of the porcelain was observed. The new cognitive fabrication method produces restorations with a satisfying clinical performance in the anterior and posterior region.

***Keywords:** CAD/CAM; Zirconia; Chipresistant Porcelain; Cognitive Production; Clinical Study; Long-Term Fatigue Study*

Introduction

With the increasing consideration of aesthetics and biocompatibility, all-ceramic restorations have gained great popularity in dentistry. Simultaneous with the introduction of zirconia as a dental restorative base, computer-assisted production has been given a new boost to CAD/cam, with the result that most of the restorations are now zirconia-based or otherwise all-ceramic [1]. Chipping of the veneering ceramics, the most commonly reported complication of veneered zirconia restorations, is mostly attributed to substructure design and inadequate cooling during the veneering process. It is surprising that the low intrinsic strength of porcelain is often an overlooked cause of chipping. In the case of the presence of a crystalline phase, e.g. Leucite, the chipping of the veneering ceramic can be easily prevented. This article describes the Primero system for ceramic restorations, which uses „chipresistant" porcelain from the beginning. The 6-year clinical trial showed a completely satisfactory clinical performance, with no chipping of the veneering ceramics. In order to exclude chipping of the veneering ceramic, the dental technology has changed without any regard to monolithic restorations, which can not bring the aesthetics and biocompatibility of layered restorations. Chipresistant porcelain and innovative technology are allow for six years of durable layered restorations that can be inexpensively manufactured using cognitive technologies. This technology ends the never-ending quest for biomimetic aesthetics with CAD / CAM [2-4], with a focus on laying the hardness in the enamel corridor while retaining the benefits of ceramic materials.

Histo-anatomical structure

One of the great advantages of computer-aided fabrication of dentures is the ability to copy the histo-anatomical tooth structure with three-dimensional information about the exterior and interior design of natural teeth. This information forms the basis for the production of layered Primero restorations. Korenhof [5] found that there is a dynamic relationship between the dentin enamel border (DEB) and the outer surface of a natural tooth: DEB contains important information about the outer surface of the tooth. Conversely, this can also allow a determination of the interior design (DEB) of the outer surface (Figure 1). The outer and inner geometry are dynamically connected. This means that a virtual change of the outer surface in the CAD software automatically leads to a change in the corresponding internal structure.

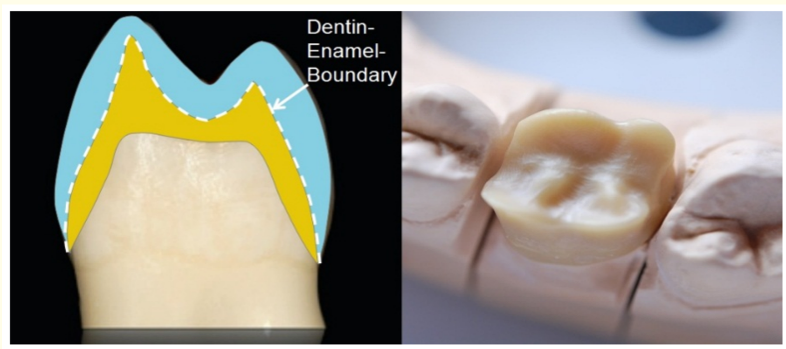

Figure 1: *Histo-anatomical substructure of a Primero® crown.*

Monolithic zirconia

Chipping [6] and delamination [7] of porcelain veneering has forced dental technology to provide monolithic zirconia, despite its severe clinical deficiencies such as hardness, which is more than twice that of porcelain and less suitable optical properties [8]. This becomes a problem, especially if a front crown or short span bridge is placed next to natural teeth. The temporary approach to this problem is to introduce an optically isotropic cubic zirconia material (e.g. Zpex Smile from Tosoh Corporation). However, biphasic tetragonal/cubic zirconia is weaker and more brittle compared to its tetragonal counterpart. In this case, reflectance and light scattering are not natural, unlike zirconia (Figure 2).

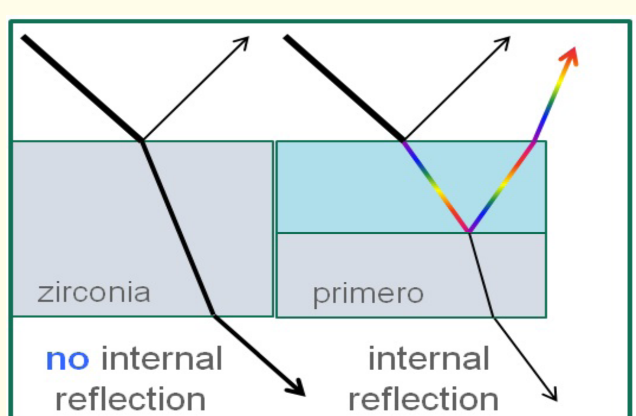

Figure 2: *The passage of light is more lively in Primero by internal reflection.*

Biocorrosion

The aesthetic results of PRIMERO restorations can be described as excellent. The crowns and bridges exhibit light dynamics similar to that of natural teeth. This is probably caused by scattering of the light on the dentine core which leads to different effects in the incisal area (Figure 1). Because of the high translucency of the porcelain the presence of apatite crystals give the enamel an opal effect (blue absorption), in the incisal area, like it occurs in a natural tooth. Because densely compressed zirconia it is much easier to mill to sharp edges, than with brittle, pre-sintered zirconia blocks, the copings and bridge substructures are not weakened by corrective grinding of the marginal edge after sintering. As a result, supra-gingival minimal invasive preparations, such as knife edge (extended bevel preparation) are possibly without the risk of the outbreak of the marginal edge [9].

Due to contact with the unforgiving hardness of uncovered zirconia in the occlusal region, antagonists show fine cracks in the enamel layer after several years. This damage, in combination with the acids in the mouth, accelerates the biocorrosion of the antagonists. The hardness of Primero Enamel, like other physical properties, is similar to that of natural melt (Table 1) and will naturally abrade due to its hydrolyzed surface. In proven chewing simulations, Primero Enamel shows an abrasion behavior similar to tooth enamel [10], in contrast to monolithic zirconia, which do not allow contact wear.

Property:		Natural enamel			Primero Enamel			Zirconia
Kleur	Lab-value	L*	a*	b*	L*	a*	b*	
	against white background	76,3	3,4	17,2	73,4	2,7	19,1	
	against black background	63,5	0,8	10,7	61,0	0,6	12,1	
Transparency (1 mm), %		64,4			65,1			32,5
Opalescense		7,00			7,31			0,00
Refractive index, n_i		1,6			1,5			2,2
Vickers' hardness, HV		440			470			1200

Table 1: *Comparison of properties of natural enamel, Primero Enamel and zirconia.*

2Hue® color system

The color and color gradients of a Primero restoration result from the base color (16 cervix colors) of the zirconia core and the variation in the layer thickness of the Primero Enamel porcelain [11]. This flexibility in the 2Hue color system is not possible with monolithic restorations due to the massive stratification of the different colors in the solid milling block. An important advantage of the Primero crowns and bridges over translucent monolithic restorations is that the color of the restoration, due to masking of the zirconia substructure, is not affected by the cement color or a discolored stump, so that the design color exactly matches the color in the mouth. Tetragonal zirconia, unlike cubic zirconia, is birefringent, meaning that the refractive index is anisotropic in different crystallographic directions [12]. This property causes reflection and refraction at the grain boundaries, thereby reducing the light transmittance. The liveliness of the Primero restorations, unlike monolithic restorations, is achieved by a highly transparent porcelain layer, which is also responsible for the natural fluorescence and opalescence.

Chipresistant porcelain

The sensitivity to chipping of ceramic veneering on zirconia can be tested in the laboratory after thermal cycling and mechanical stress [6]. Molars were placed to create a mandibular posterior situation (teeth 5/7) with a 10 mm gap in the mouth. Human teeth of comparable size and root dimensions were used. In addition, teeth ensure a clinically relevant modulus of elasticity of the abutments and ensure a relevant interface between fixed partial dentures and teeth. Different dimensions of the teeth were therefore tolerated. All teeth were prepared according to the guidelines for ceramic restoration techniques with a depth of 1 mm circular shoulder crown preparation. Eight tripartite veneered bridges would be cemented with glass ionomer cement. The loading parameters were: 1,200,000 mechanical loads of 50N and 6,000 thermal cycles between 5°C and 55 C, which simulate five years orally. The simulation time was extended to 3,600,000 in a second and third run. In the fracture test, the bridges are loaded until failure with a testing machine. The force was used with a steel ball (d = 12 mm) and a 1 mm thick tin foil, applied between pontic and antagonist, was used to prevent force peaks. Eight tripartite Primero bridges veneered with Primero® Enamel (Sakura® Interaction, Elephant Dental, Hoorn-NL) were the only ones without chipping, unlike bridges that were veneered with other commercially available porcelains, that showed 12.5 - 100% chipping of the ceramic veneer during the aging test. The chip resistance of Primero Enamel is due to the presence of a high-melting leucite phase in the porcelain matrix, which acts as dispersion hardening and crack-stopper and therefore resists the high stresses that build up after cooling by the resistant zirconia. Leucite crystallizes without significant impairment of translucency because the refractive index of leucite (n = 1.51) is very close to that of porcelain. Clinical studies have shown that feldspar ceramic restorations are very successful in the long term. For example, the survival rate of inlays and onlays is 92% at 8 years, 34 veneers 94% at 12 years, 35 and crowns 95% at 11 years [12]. The average breaking strength of the Primero bridges after aging was 1440N, in comparison with 533 to 1380 N for the other veneered bridges. The histo-anatomical structure of the Primero crowns has a positive effect on the load capacity, since the relatively thin, uniform porcelain layer is optimally supported by the zirconia substructure [13].

Primero Enamel properties

The adhesion of Primero Enamel to zirconia was measured by the test described in ISO/CD 9693 (Schwickerath crack initiation test) and gave a significantly higher value of 45.2 ± 3.5 MPa, compared to 30.6 ± 1.49 MPa or 36.1 ± 1.28 MPa for NoritakeZR-zirconia and DegudentU-Vita combinations. The high adhesive strength is due to the presence of a low melting phase in the porcelain matrix which causes better wetting of the surface of the zirconia [14].

Typically, glass-ceramics have a Vickers surface hardness of 600-700. Due to the presence of the low-melting glass component, Primero Enamel shows a hydrothermal reaction with water by exchanging mainly sodium ions in the porcelain with water from saliva. This hydrolysis increases the water content of the compact and smooth outer surface of the porcelain from about 200 to 650 ppm water with an inherent Vickers hardness reduction from 600 to 470, which is very close to the hardness of natural enamel (Table 1) [15].

Results of the six year clinical study

The study aiming to clinically assess Primero crowns and bridges was structured on the basis of a previous study of three-layered single crowns at the Academisch Centrum voor Tandheelkunde Amsterdam (ACTA) [16]. In a 6-year prospective clinical study, crowns and bridges produced by the Primero CAD/CAM system were evaluated. After a year, a first evaluation took place [9]. The medical-ethical committee of the University Hospital of the University of Amsterdam approved the study. In January 2012, patients in a general dental practice who needed an individual fixed prosthetic restoration were selected and invited to participate in this clinical trial. They received a brief description of the CAD/CAM system and a written consent was obtained. Finally, each patient was asked to complete a questionnaire with questions about overall satisfaction, color, shape and comfort. In 155 patients, 190 Primero elements were prepared and cemented on incisors (7), canines (6), premolars (81), molars (96), including 4 two-, 9 three- and 2 four-unit bridges, and were after six years assessed with a modified version of the California Dental Association (CDA) criteria. To evaluate the color, each crown was scored in three independent areas, cervical, buccal and occlusal. The radiographic evaluation was based on the comparison between the initial periapical radiographs (April 2012) and those after six years. Two independent reviewers compared and evaluated each radiograph. If the assessments were different, the appraisers resolved their disagreement through joint testing. No tooth decay was recorded. In 91% of the cases, the dentists considered the crowns to be very esthetic. The patients noticed the crowns with excellent aesthetics. During the observation period, however, two Primero crowns (1.0%) showed small fractures of the veneering ceramics. None of the restorations showed any breaks. According to the questionnaire, all patients were satisfied or very satisfied with their all-ceramic restorations.

Due to the fact that there were only minor technical complications, the clinical performance of Primero crowns and bridges in the anterior and posterior region was completely satisfactory.

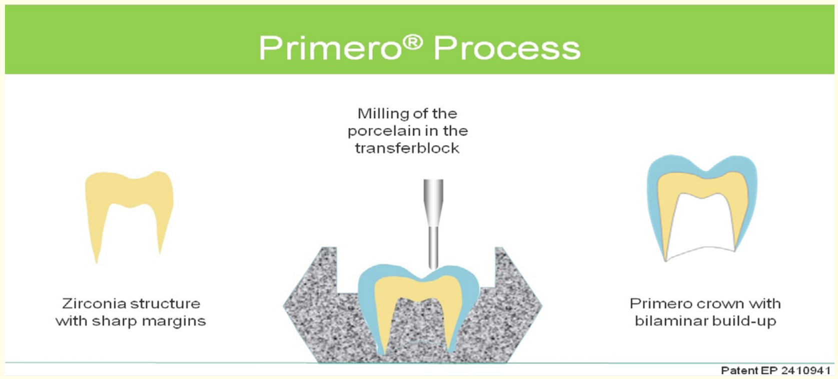

Figure 3: *Schematic overview of the Primero process.*

Production process

Primero production takes place in four activity domains (Figure 4):

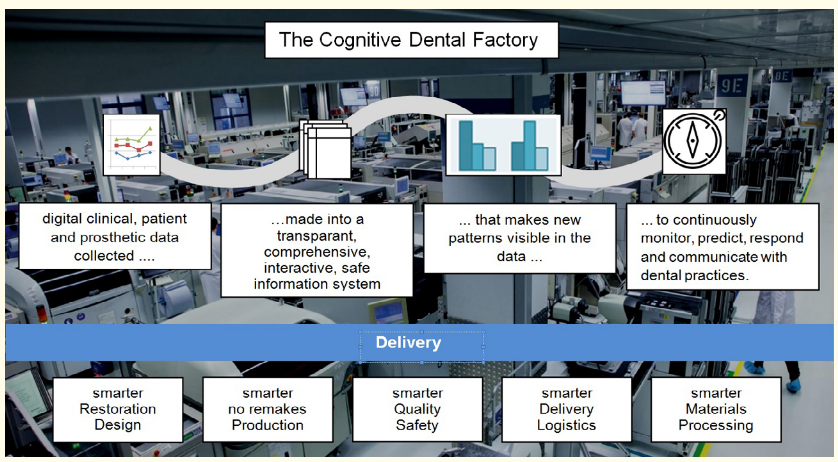

Figure 4: *Cognitive production leads to smarter designs, fewer outages, higher quality, better logistics and lower costs.*

- **Digital clinical, patient, and prosthetic data collection:** The information for a given restoration for a particular patient from a particular dentist is delivered digitally, but may also be accompanied by a scannable „3-in-1“ impression. The collected data is checked for completeness and marked with a product number upon acceptance.
- **A transparent, comprehensive, interactive, secure information system:** As soon as the restoration information arrives as a Weborder, the information system will check whether the order is in detail of the previously established method of operation of the dentist (current CustomerWishProfile) in terms of design (e.g. contact points) and Finishing (e.g. surface) and the order is adjusted. The information system reproduces the human way of processing information and thus enables the implementation of an intelligent control system that is able to map complex cause-and-effect relationships as well as an inherent ability to adapt to changing environmental conditions.
- **New patterns visible in the data:** If a change in the restoration requirements a pattern is displayed, the customer request profile in the information system, after consultation with the dentist adjusted. This creates a self-optimizing system that has the required flexibility and versatility.
- **Continuous monitoring:** In the context of the customer satisfaction analysis, the resulting results are used to adjust certain parameters (for example, layer thickness of the porcelain layer).

Cognitive production

The manufacturing process of highly esthetic veneered restorations with tooth-colored materials is currently dominated by manual, cost-sensitive production methods, the results of which depend heavily on the knowledge and skills of the dental technician. The production technology of crowns and bridges in high-wage countries is currently facing challenges: Customers are increasingly demanding products that are characterized by a high number of variants and a high degree of complexity. Furthermore, the general conditions of the international markets are increasingly characterized by increasing change and cost pressure by cheap labor from low-wage countries. Complex products and processes as well as an increasing diversity of variants place new demands on modern so-called cognitive systems for production control (Figure 4). The system must be able to produce crowns and bridges efficiently and with stable quality. In addition, the process requires a high degree of flexibility and versatility. These requirements are not fully met by currently common technologies, resulting in numerous rework or even reject rates.

To make the most of this potential, close collaboration between the dentist and Cyrtina is required. An important role is played by the CustomerWishProfile and the digital Weborder. This information is available for the system operator. The reject rates could be greatly reduced by the introduction of cognitive production.

Discussion

The current procedure describes the production of permanent layered restorations using an innovative, simple method based on the copy of the histo-anatomical natural tooth structure. This makes the fabrication fast and predictable and is suitable for cognitive production of layered restorations in the aesthetic area. The cost of the production process can be evaluated as very cost effective compared to manually attaching porcelain by a dental technician. The products even surpass their natural model in their optical behavior. In addition, the manufacturing effort compared to other known methods for layered restorations such as press-fitting technique and digital veneering by joining a sintered firing from a tooth-colored glass cap to a zirconia cap is considerably simplified [17-19]. The latter technique, when there are undercuts in the dentin core, makes it impossible to match the outer part to the zirconia cap. In the Primero process, the porcelain is pressed by the centrifugal force into the negative form and thus reaches all undercut areas correctly (Figure 3).

Conclusion

The histo-anatomy of the tooth implies that the dentin core is the key to the digitally-generated aesthetics. The generation of the individual 3D tooth structure, including the dentine-enamel border (DEB), is determined by a mathematical model of the local layer thickness of the veneer. Interference in the local layer thickness determines whether the color has to be darkened (thinner) or brightened (thicker). Therefore, monolithic zirconia with a fixed color layers in the milling block is not flexible enough for cognitive production. The bilaminar technique simulates the color gradients more naturally than is possible with graded monolithic zirconia. The Primero model is suitable for cognitive technology to achieve compelling aesthetic results. Chipping of the veneering ceramics did not occur during a six-year observation period and the clinical performance of Primero crowns and bridges in the anterior and posterior region was fully satisfactory.

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