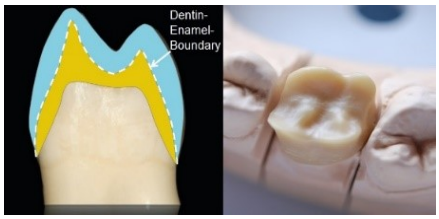
Cognitive Design of Crowns and Bridges

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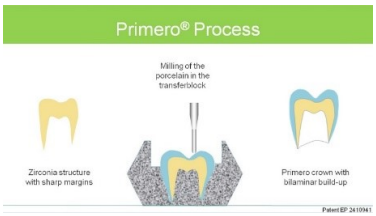
Introduction

The manufacturing-process of high-aesthetic restorations from tooth-coloured restorative materials is currently dominated by manual manufacturing procedures and the outcome is highly dependent on the knowledge and skills of the performing dental technician. Two-layered crowns and bridges can be produced by the Primero® process with a substructure of zirconia veneered with a non-chipping porcelain. To design an aesthetic crown in two layers a mathematical model of the general dentin-enamel boundary (DEB) is combined with an enamel layer thickness model for visual individualization effects. This research is sponsored by the Foundation of Oral Restorative Technologies (ORESTES, Hoorn, The Netherlands).



Material and methods

- Sixty disks of Prmero Enamel porcelain with a translucency of 63% (d = 1.00 mm) were fabricated five groups, with a thicknesses of 0.20, 0.40, 0.60 and 0.80 mm. The disks were placed on a background of zirconia in three cervix colors (A1, A2, and A3) respectively. The L*a*b*- CIE-lab color parameters were determined by a Coloreye® spectrophotometer (Olympus, Japan). The bi-layered restorations were designed with an dentin-enamel boundary (DEB) that corresponded with the original natural element. A mathematical model was derived from the measurements resulting in an equation that predicts the resulting color from the enamel thickness.
- Three anterior crowns were produced in Vita A1, A2 and A3 color, with the Primero process and the substructure library model. Three different cervix colored zirconia substructures in zA1, zA2, zA3 were used with the same transparent enamel porcelain. After production the crowns were evaluated for any anomalies, like bubbles or whiteness. The color was measured with a Coloreye® spectrophotometer (Olympus, Japan). The overall color and appearance was compared with the Vita Classic color guide for matching.



The Primero® process

The fabrication of crowns and bridges starts by milling and sintering the zirconia substructures, which are 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 topside milled and fired.

Results

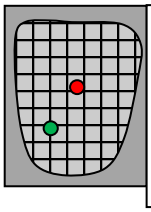
I. Substructure library model: Boundary between dentine and enamel derived from patient data

A histo-anatomic layer build-up of crowns and bridges similar to natural teeth was developed (Schweiger et al.,Histo-anatomic 3D printing of dental structures. November 2016, British dental journal 221(9):555-560). Taking the example of manufacturing replicas of extracted intact natural teeth a substructure library model could be build. Examples of some design elements that have can be extracted from big data on dental patient cases:

Parameter	Range	Porcelain design element parameterization
Age of patient (A_p)	20-80 years	Occlusal thickness: $d_o = 0.2 + (80 - A_p) * 0.02$
Mesio-distal distance (a_{md})	5-14 mm	Mesio-distal thickness: $d_{md} = 0.6 * (14 - a_{md}) / 14)$

II. Color differention model: Color darkening is realized by decreasing enamel thickness

The L_r*-value at the reference point is, where the thickness of the enamel is 0.60 mm to give the exact overall color. At a random measured point the L_m*-value relates to a particular enamel thickness d_m. For the purpose of determining the location a wiremesh is projected on the visible side of the adjacent tooth.

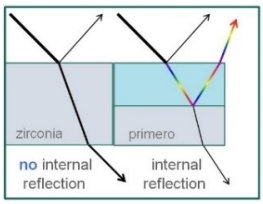


Calculation of local porcelain thickness (d_m), on the basis of L-value for lightness at that locality (L_m)

- **Reference point** with L-value, L_r; thickness, d_r = 0.60 mm
- **Measured point** with L-value, L_m; thickness d_m is calculated:

$d_m = d_r - | L_r - L_m | * d_r * 0.04$ mm, where d_r = 0.60 mm

Two observers found more than 90% match of color to the VITA Classic color guide



A histo-anatomic two-layered structure reflects the light in a similar way as in natural teeth. The bilaminar technique simulates the color gradients more naturally than is possible with graded monolithic zirconia, where the color is fixed in a solid block of material.

Discussion

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. 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 boundary (DEB) and the local enamel thickness, is determined by a combined mathematical model for the local enamel layer thickness of the veneer. Interference in the local layer thickness determines whether the color has to be darkened (thinner) or brightened (thicker). Therefore, the popular color-graded monolithic zirconia, which has fixed color layers in the milling block is not flexible enough for cognitive production. There is a general fear for chipping of veneering porcelain on zirconia. However, chipping of the veneering ceramics did not occur during a six-year clinical observation period of Primero® crowns and bridges and the clinical performance in the anterior and posterior region was fully satisfactory. The agreement with the Vita Classic colour guide appeared sufficient (better than 90% by 2 observers).

Conclusion

The Primero® process enables the production of durable histo-anatomical restorations. However, these crowns and bridges still have to be designed by trained dental technicians. This study offers two algorithms that reduce the efforts with a cognitive design process for an attractive and natural aesthetic result.