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# Influence of layering thickness on the color parameters of a ceramic system

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## ARTICLE INFO

### Article history:

Received 29 July 2009

Received in revised form

1 February 2010

Accepted 21 March 2010

### Keywords:

Dental materials

Fixed prosthodontics

Color

Porcelain fused to metal

Hue

Saturation

Value

Clinical spectrophotometer

## ABSTRACT

**Objectives.** The aim of this study was to establish by means of a spectrophotometer the influence of each layer of a porcelain fused to metal (PFM) ceramic system on the color parameters (Lightness, Chroma and Hue) of the final restoration.

**Methods.** One ceramic system (Vita VM13, Vita Zahnfabrik, Bad Säckingen, Germany) was evaluated. 40 ceramic discs were fabricated with a proprietary steel mold and individually checked after firing with a digital calliper to control the thickness of each layer. 4 different total ceramic thicknesses in 2M3 shade were evaluated. For each thickness 2 different layering patterns were analyzed. The layering thickness range for Base Dentin was 0.25–0.90 mm, for Transpa Dentin 0.35–0.75 mm, for Enamel 0.15–0.50 mm. Easyshade (Vita Zahnfabrik) clinical spectrophotometer was used for color comparison with the reference color data of the selected shade stored into the device.

**Results.** One-way ANOVAs showed that the factor 'layering pattern' significantly influenced the  $\Delta E$ ,  $\Delta C$ ,  $\Delta H$  and  $\Delta L$  ( $p < 0.001$ ). Greater thicknesses of Base Dentin resulted in a more Chromatic shade. Conversely, greater thicknesses of Transpa Dentin and Enamel reduced the Chroma of the color. An increase in the Enamel layer thickness resulted in a reduction of the Lightness (Value) and vice-versa.

**Significance.** The variation in thickness of the various layers significantly influenced the final color of the artifact. The variation found should be taken into account in order to obtain the aimed shade, in relationship with the total thickness of the ceramic veneer.

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## 1. Introduction

The achievement of natural looking restorations has always been one of the greatest challenges in restorative and prosthetic dentistry. The integration of the restoration with the biological tissues and the attainment of normal function are the goals that clinicians and technicians aspire to in everyday dental practice.

Dental porcelain, combining wear resistance, strength, toughness and aesthetics is at present the most suitable material for replacing natural tissue, even if it is not easy to handle and aesthetic excellence is not always easy to obtain [1–3]. Therefore the ceramic veneering procedure is often considered to be an art form. The first step for the best aesthetic reproduction of a tooth is shade selection, traditionally carried out with dental shade guides.

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doi:10.1016/j.dental.2010.03.018

**Table 1 – Layering patterns of the ceramic specimens.**

| Sample | LP <sup>a</sup> | Alloy (mm) | Opaque (mm) | Base Dentin (mm) | Transpa Dentin (mm) | Enamel (mm) | Final (mm) | Ratio |
|--------|-----------------|------------|-------------|------------------|---------------------|-------------|------------|-------|
| 1–5    | 1               | 0.30       | 0.15        | 0.35             | 0.35                | 0.15        | 1.30       | 1:1   |
| 6–10   | 2               | 0.30       | 0.15        | 0.25             | 0.45                | 0.15        | 1.30       | 1:2   |
| 11–15  | 3               | 0.30       | 0.15        | 0.30             | 0.65                | 0.20        | 1.60       | 1:2   |
| 16–20  | 4               | 0.30       | 0.15        | 0.45             | 0.50                | 0.20        | 1.60       | 1:1   |
| 21–25  | 5               | 0.30       | 0.15        | 0.40             | 0.75                | 0.30        | 1.90       | 1:2   |
| 26–30  | 6               | 0.30       | 0.15        | 0.75             | 0.40                | 0.30        | 1.90       | 2:1   |
| 31–35  | 7               | 0.30       | 0.15        | 0.70             | 0.65                | 0.50        | 2.30       | 1:1   |
| 36–40  | 8               | 0.30       | 0.15        | 0.90             | 0.45                | 0.50        | 2.30       | 2:1   |

<sup>a</sup> LP, layering pattern.

Shade selection has been the subject of several investigations [4–7], and since it cannot be considered a purely scientific procedure, it is often considered as one of the weakest links in achieving aesthetic excellence. Even when an appropriate shade has been selected, the laboratory reproduction and manufacture of the restoration still remain quite a difficult procedure. Douglas and Brewer found that the ability to reproduce the color of the target shade tab differed among laboratories and that most of the crowns fabricated by the laboratories in their study were above the clinical threshold for an acceptable shade match ( $\Delta E = 3.7$ ) when compared to the prescribed shade tab [8]. This is probably due to the long list of factors that are relevant in influencing the final color of the porcelain restorations, such as firing [9], glazing [10], the mixing ratio between powder and liquid [11], different substructures [12] and layering [13,14]. Dozic et al. investigated the influence of porcelain layer thickness on the final shade of metal free ceramic restorations, finding a significant correlation between the thickness ratio of the opaque/veneering porcelain system within 1.00 mm and color coordinates  $a^*$  and  $b^*$  and that the correlation of the  $L^*$  value with thickness of opaque and translucent porcelains was shade dependent [13]. Jarad et al. in an in vitro study found that a change in enamel porcelain thickness had a greater effect on higher chromatic shades than those with lower chroma, and the reduction of the enamel thickness produced three-dimensional color changes (lightness, hue angle and metric chroma) [14]. Corciolani et al. in a previous study found that the layering pattern, concerning different ratios between veneering layers of metal ceramic crowns, significantly influenced the final color of the restoration [15].

The aim of this study was to establish by means of a clinical spectrophotometer the relative influence of each layer of porcelain fused to metal (PFM) restorations on the color parameters (Lightness, Chroma and Hue) of the final restoration.

The formulated null hypothesis was that the thickness of each layer did not significantly influence the final color of the PFM restorations.

## 2. Materials and methods

The ceramic system selected for this study was Vita VM13 (Vita Zahnfabrik, Bad Säckingen, Germany) based on the Vita 3D-Master Toothguide (Vita Zahnfabrik).

The stand-alone clinical spectrophotometer VITA Easyshade (Vita Zahnfabrik) was used to measure color

differences. The repeatability of color readings and therefore the validity of this clinical spectrophotometer for research purposes were previously tested [16]. Easyshade's measurement technique utilizes large diameter fiber optics arranged in a specific patented design in a stainless steel probe. This fiber optics arrangement allows analyzing a deeper area and not limiting to a measurement of the surface. The probe has a circular reading spot of 5 mm in diameter, which is smaller when compared to other spectrophotometers. The instrument can perform measurements in two different ways, which the operator can select. Substantially, the reading fibers are at the center of the probe; then, there are two different fiber optics arrays by which the illumination may be carried. When measuring a natural tooth, the outer area of fiber optics carries the light, so that the light is reflected from an area that is centered at approximately 2.0 mm distance from the surface level. When measuring a ceramic restoration the light is carried by a more internal array of fiber optics, so the area measured is closer to the surface, and this is the case of a ceramic restoration, where the thickness is generally less than 2.0 mm.

The Easyshade is powered with an internal light source and environmental lighting conditions do not influence the Easyshade color measurements. Anyway, the readings were performed in an artificial illuminated room, without any natural lighting, so the environmental light was always the same. In order to verify the influence of the thickness of each layer of a restoration on the various color parameters, 40 ceramic discs were fabricated in 8 different layer thicknesses (Table 1).

For preparing the metal substrates, self-curing acrylic resin discs (DuraLay, LOT 052802, Reliance Dental Manufacturing Co., Worth, IL, USA), 0.3 mm in thickness and 15 mm in diameter were made in a cylindrical stainless steel mold (Fig. 1). After placing the material into the mold, a glass plate was pressed onto the superficial layer in order to obtain a flat surface. After curing, the resin sample was extracted from the mold, put in a refractory cast filled with investment (GC Stellavest, GC Europe, Leuven, Belgium), and placed in a burnout furnace (Ovomat 7, Manfredi-SAED, Turin, Italy).

At the end of the burnout cycle, the investment was moved to an induction casting machine (Enterprise, Jelrus, Hicksville, NY, USA), and filled with a base metal alloy (Biomate-C, Silpo, Rome, Italy).

The resulting disc-shaped specimens were roughened with a sandblaster (Skylab, Tecnogaz, Parma, Italy), using  $AlO_2$  particles of 100  $\mu m$  diameter at 6 bar of pressure.



**Fig. 1 – Calibrated mold used for manufacturing specimens in controlled thickness.**

### 2.1. Procedure for manufacturing specimens

Flat disc specimens were used in the study in order to facilitate the process of obtaining controlled thicknesses of the different ceramic layers, since Barrett et al. found no statistically significant differences in shade-matching accuracy between tab and disk design [17].

The color selected for the layering procedure of the 40 samples was 2M3 in the Vita 3D-Master Toothguide. Following the manufacturer's instructions, for each sample a wash opaque layer was applied first and fired in a ceramic oven (Vacumat 4000, Vita Zahnfabrik). Then, a second opaque layer was added and fired. At this stage the first opaque dentin layer was applied in a thickness controlled by the mold and fired following the manufacturer's firing instructions. A second dentin layer was subsequently stratified and fired. The enamel layer was also stratified and fired in the ceramic oven. The veneering materials were produced by the same manufacturer (Vita Zahnfabrik) and they are shown in Table 2. Finally, for each

sample, a glaze firing was applied according to the ceramic manufacturer's instructions.

A controlled thickness of the veneering materials was achieved. Layering the ceramic into a calibrated mold with a 0.1 mm resolution allowed for a predictable thickness of each layer to be obtained. This was measured by an electronic digital caliper (1651 DGT, Beta, Milan, Italy) with a 10  $\mu\text{m}$  resolution, after the firing process. The thickness of each layer was considered acceptable for the study only when the variation in thickness was  $\pm 20 \mu\text{m}$ . The diameter of the disc was chosen of 15 mm in order to avoid the influence of the ceramic irregularities that sometimes were found along the peripheral area of the discs after the firing, considering that the reading area of the instrument is 5 mm.

The thicknesses of the specimens are shown in Table 1. These layering patterns followed the “Vita VM13 Build Up Layering” basic instructions and the variations were selected on the basis of the recommendations of the manufacturer [18].

### 2.2. Spectrophotometric measurements

The spectrophotometer Vita Easyshade comprises a base unit and a hand piece. The color evaluation was carried out by fixing the instrument on a stand, as in a previous study it was shown that this set-up led to an higher repeatability of readings than the free-hand use [16]. All the measurements were performed keeping the tip of the spectrophotometer perpendicular to the discs and in contact with the discs surface.

All the measurements were consecutively performed after only one calibration process in order to standardize the reproducibility. “Restoration” mode was selected on the spectrophotometer and was used throughout. The instrument has stored in its memory the values of each shade of the Vita-pan Classical and Vita 3D-Master Toothguide. In “Restoration” mode, the instrument measures the values of the tested object (the disc in this case), then compares these values with the stored data and provides as screen output the differences for Chroma ( $\Delta C$ ), Hue ( $\Delta H$ ), Lightness ( $\Delta L$ ) and general error ( $\Delta E$ ). These differences are calculated by the spectrophotometer according to the formula proposed by Clarke [19].

### 2.3. Statistical analysis

$\Delta E$ ,  $\Delta C$ ,  $\Delta H$  and  $\Delta L$  values were statistically analyzed. Normality of data distribution and variance homogeneity in the groups was preliminarily verified using the Kolmogorov–Smirnov test and the Levene test respectively. In order to determine the significance of the differences in color correspondence, recorded by the eight groups, four One-way Analysis of Variance tests were applied, assuming respectively  $\Delta E$ ,  $\Delta C$ ,  $\Delta H$  and  $\Delta L$  as the dependent variables and the layering pattern as factor. The Tukey HSD test was applied for post hoc comparisons. In all the analyses the level of significance was set at  $p < 0.05$ .

## 3. Results

Table 3 shows the color values measured with the Vita Easyshade spectrophotometer for Vita VM13 in 2M3 shade.

**Table 2 – Materials used for veneering procedures.**

|                | VM 13                    | Batch |
|----------------|--------------------------|-------|
| Wash Opaque    | WO Wash Opaque Paste 359 | 7666  |
| Opaque         | OP2 Opaque Paste 352     | 7739  |
| Base Dentin    | 2M3 Base Dentine 040     | 7516  |
| Transpa Dentin | 2M3 Transpa Dentine 070  | 7468  |
| Enamel         | ENL Enamel 191           | 7933  |

**Table 3 – Vita Easyshade color evaluation of VM13 ceramic system in 2M3 shade. Measurements were performed in “Restoration” mode. Delta values represent the differences with standard color parameters for the selected shade set in the instrument.**

| LP <sup>a</sup> | Thickness (mm) | Ratio | Sample | $\Delta E$ | $\Delta C$ | $\Delta H$ | $\Delta L$ |
|-----------------|----------------|-------|--------|------------|------------|------------|------------|
| 1               | 1.3            | 1:1   | 1      | 1.0        | −0.2       | −1.0       | 0.9        |
|                 |                |       | 2      | 1.1        | −0.2       | −0.9       | 1.0        |
|                 |                |       | 3      | 0.8        | −0.5       | −0.7       | 0.5        |
|                 |                |       | 4      | 1.1        | −0.5       | −0.8       | 0.9        |
|                 |                |       | 5      | 0.8        | −0.2       | −0.8       | 0.8        |
| 2               | 1.3            | 1:2   | 6      | 2.4        | −1.3       | 0.0        | 2.0        |
|                 |                |       | 7      | 2.0        | −0.9       | −0.1       | 1.8        |
|                 |                |       | 8      | 2.0        | −1.1       | 0.1        | 1.6        |
|                 |                |       | 9      | 2.1        | −1.2       | 0.3        | 1.8        |
|                 |                |       | 10     | 1.6        | −0.8       | −0.1       | 1.4        |
| 3               | 1.6            | 1:2   | 11     | 0.7        | −0.4       | −0.6       | −0.5       |
|                 |                |       | 12     | 0.6        | −0.4       | −0.7       | −0.4       |
|                 |                |       | 13     | 0.8        | −0.3       | −0.7       | −0.7       |
|                 |                |       | 14     | 0.8        | −0.4       | −0.7       | −0.6       |
|                 |                |       | 15     | 0.7        | −0.5       | −0.6       | −0.5       |
| 4               | 1.6            | 1:1   | 16     | 1.6        | 0.2        | −1.3       | 1.5        |
|                 |                |       | 17     | 1.9        | 0.2        | −1.4       | 1.8        |
|                 |                |       | 18     | 1.6        | 0.1        | −1.2       | 1.5        |
|                 |                |       | 19     | 1.6        | 0.2        | −1.3       | 1.5        |
|                 |                |       | 20     | 1.8        | 0.3        | −1.3       | 1.7        |
| 5               | 1.9            | 1:2   | 21     | 2.1        | −2.0       | −2.2       | 0.0        |
|                 |                |       | 22     | 2.3        | −2.1       | −2.2       | −0.1       |
|                 |                |       | 23     | 2.4        | −2.2       | −2.3       | 0.1        |
|                 |                |       | 24     | 2.4        | −2.3       | −2.3       | 0.1        |
|                 |                |       | 25     | 2.4        | −2.3       | −2.4       | 0.1        |
| 6               | 1.9            | 2:1   | 26     | 1.0        | 0.0        | −2.6       | −0.4       |
|                 |                |       | 27     | 1.1        | −0.3       | −2.7       | −0.3       |
|                 |                |       | 28     | 1.1        | −0.1       | −2.6       | −0.5       |
|                 |                |       | 29     | 1.1        | −0.3       | −2.5       | −0.5       |
|                 |                |       | 30     | 1.1        | −0.3       | −2.6       | −0.5       |
| 7               | 2.3            | 1:1   | 31     | 4.2        | −3.9       | −4.1       | −0.3       |
|                 |                |       | 32     | 4.2        | −3.9       | −4.3       | −0.5       |
|                 |                |       | 33     | 4.3        | −4.0       | −4.3       | −0.4       |
|                 |                |       | 34     | 4.2        | −3.9       | −4.3       | −0.4       |
|                 |                |       | 35     | 4.3        | −4.1       | −4.3       | −0.2       |
| 8               | 2.3            | 2:1   | 36     | 2.6        | −2.4       | −2.5       | −0.5       |
|                 |                |       | 37     | 2.5        | −2.3       | −2.6       | −0.5       |
|                 |                |       | 38     | 2.5        | −2.3       | −2.6       | −0.6       |
|                 |                |       | 39     | 2.5        | −2.3       | −2.5       | −0.6       |
|                 |                |       | 40     | 2.5        | −2.3       | −2.6       | −0.5       |

<sup>a</sup> LP, layering pattern.

In the first column the scanning data for each sample are indicated. In the other columns there are values of Delta related to Lightness, Chroma, Hue, and  $\Delta E$ , because the Easyshade spectrophotometer makes comparison measurements.

The Kolmogorov–Smirnov test revealed that the recorded data were normally distributed ( $p > 0.05$ ).

One-way ANOVA showed that the factor “layering pattern” significantly influenced the  $\Delta E$ ,  $\Delta C$ ,  $\Delta H$  and  $\Delta L$  ( $p < 0.001$ ). When evaluated at the univariate level (homogeneity of variances assessed by the Levene test  $p > 0.05$ ), the factor “layering pattern” resulted in the significant interactions highlighted in Table 4 (Tukey test for pairwise comparisons,  $p < 0.05$ ).

#### 4. Discussion

The differences found in the color parameters and Delta values between the different layering patterns analyzed, support the rejection of the null hypothesis.

Color can be measured in different systems, like CIELab\*, CIELuv, XYZ, Lch, HSB/HSV, RGB. All these systems differ mathematically, but may be correlated to each other by the use of conversion formulas. For scientific purposes, the most commonly used approach is the CIELab\* system, in which  $L^*$  value is the degree of lightness of an object,  $a^*$  value is the degree of redness or greenness, and  $b^*$  value is the degree of yellowness or blueness [20].

**Table 4 – Descriptive statistics of the  $\Delta C$ ,  $\Delta H$ ,  $\Delta L$  and  $\Delta E$  values recorded in the experimental groups. In the significance column, different superscript letters label significant differences when the ceramic system layering pattern ( $^{\circ}$ LP) interactions were assessed at the univariate level.**

| LP <sup>a</sup> | n | $\Delta C$   |     | $\Delta H$   |     | $\Delta L$   |     | $\Delta E$  |     |
|-----------------|---|--------------|-----|--------------|-----|--------------|-----|-------------|-----|
|                 |   | Mean (SD)    | Sig | Mean (SD)    | Sig | Mean (SD)    | Sig | Mean (SD)   | Sig |
| 1               | 5 | −0.32 (0.16) | a   | −0.84 (0.11) | c   | 0.82 (0.19)  | c   | 0.96 (0.15) | a,b |
| 2               | 5 | −1.06 (0.21) | b   | 0.04 (0.17)  | a   | 1.72 (0.23)  | d   | 2.02 (0.29) | d   |
| 3               | 5 | −0.40 (0.07) | a   | −0.66 (0.05) | b   | −0.54 (0.11) | b   | 0.72 (0.08) | a   |
| 4               | 5 | 0.20 (0.07)  | a   | −1.30 (0.07) | d   | 1.60 (0.14)  | d   | 1.70 (0.14) | c   |
| 5               | 5 | −2.18 (0.13) | c   | −2.28 (0.08) | e   | 0.04 (0.09)  | a   | 2.32 (0.13) | e   |
| 6               | 5 | −0.20 (0.14) | a   | −2.60 (0.07) | f   | −0.44 (0.09) | b   | 1.08 (0.04) | b   |
| 7               | 5 | −3.96 (0.09) | e   | −4.26 (0.09) | g   | −0.36 (0.11) | b   | 4.24 (0.05) | f   |
| 8               | 5 | −2.32 (0.04) | d   | −2.56 (0.05) | f   | −0.54 (0.05) | b   | 2.52 (0.04) | e   |

In dentistry, the HSB (Hue, Saturation or Chroma, Brightness or Value) system is most commonly used for color communication. For the measurements performed in this study, the HSB parameters have been individually evaluated.

Analysis of Hue [20] (defined as radial component of the cylindrical coordinates CIELab\* and calculated according to the formula  $h_{ab} = \arctan(b^*/a^*)$ ), showed that by increasing the ceramic thickness, higher values of  $\Delta H$  were obtained. It was not possible to correlate a linear relationship between Hue and the thickness of each layer. The patterns that more closely matched the standard were LP1<sup>c</sup> ( $\Delta H = -0.84 \pm 0.11$ ), LP2<sup>a</sup> ( $\Delta H = 0.04 \pm 0.17$ ) and LP3<sup>b</sup> ( $\Delta H = -0.66 \pm 0.05$ ), layered with different ratios between Base Dentin and Transpa Dentin (LP1 = 1:1, LP2 and LP3 = 1:2). It was not possible to find a direct correlation between a change in the ratio of the two dentin layers and the Hue. However, on the basis of the data obtained, it could be speculated that for the ceramic system used in this study a closer correspondence with the Hue can be obtained with smaller thicknesses.

Analysis of Saturation (or Chroma) [20] (defined as the radial component of the cylindrical coordinates CIELab\* and calculated according to the formula  $C_{ab} = \sqrt{a^2 + b^2}$ ), showed that increasing the portion of Base Dentin resulted in a higher chromatic shade, that is a more intensive final color; whereas a greater amount of Transpa Dentin and Enamel reduced the Chroma (Table 4). The LP1<sup>a</sup> (mean  $\Delta C = -0.32 \pm 0.16$ ) and the LP2<sup>b</sup> (mean  $\Delta C = -1.06 \pm 0.21$ ) are two groups with the same final thickness, but they were layered following two different patterns with regards to the ratio between Base Dentin and Transpa Dentin (LP1 = 1:1 and LP2 = 1:2). A higher thickness of Base Dentin in LP1 resulted in a closer correspondence with the Chroma parameter. This trend is also confirmed after comparing LP5<sup>c</sup> (mean  $\Delta C = -2.18 \pm 0.13$ ) with LP6<sup>a</sup> (mean  $\Delta C = -0.20 \pm 0.14$ ), where for increased thickness the pattern with a higher ratio of Base Dentin (LP6 = 2:1) resulted in the closest Chroma correspondence.

The third parameter evaluated was the Lightness (or Value), which represents the lightness–darkness of a color [20]. Value is the parameter most perceptible to the human eye, due to a greater number of rods (photoreceptor cells involved in the transduction of monochromatic light into nerve signals to the brain via the optic nerve) than cones (photoreceptor cells that detect different colors), in the human retina. For this reason, an error in this parameter will have the greatest impact on the perception of the final color. Analysis of the data obtained

in this study suggests that, for the ceramic system analyzed, the Value of a PFM restoration decreases as the thickness of the enamel layer increases. The manufacturer's instructions advice that the shade intensity can be individually adjusted by the combination of Enamel and Transpa Dentin porcelains in relation to the layer thickness of Base Dentin [18]. The analysis of LP4<sup>d</sup> ( $\Delta L = 1.60 \pm 0.14$ ) and LP7<sup>b</sup> ( $\Delta L = -0.36 \pm 0.11$ ) shows that, for two groups with the same layering ratio 1:1, that the greater thickness of the enamel layer of the LP7 caused a lower value of lightness when compared with LP4. This trend can also be seen after analyzing LP2<sup>d</sup> ( $\Delta L = 1.72 \pm 0.23$ ) and LP5<sup>a</sup> ( $\Delta L = 0.04 \pm 0.09$ ), where the latter resulted in a lower value of  $\Delta L$  and the thickness of the enamel layer was 0.30 mm.

For the ceramic system selected for this study, the ratio in thickness between Base Dentin and Transpa Dentin had a great effect on the final color. In order to understand how this ratio influenced the final color correspondence, 4 different groups with the same final thickness were layered but in different patterns (Table 4). Analyzing LP1<sup>a,b</sup> ( $\Delta E = 0.96 \pm 0.15$ ) in comparison with LP2<sup>d</sup> ( $\Delta E = 2.02 \pm 0.29$ ), where the thickness of the veneering material was 1.0 mm, the ratio of 1:1 of LP1 resulted in a closer color correspondence. When the veneering thickness was slightly increased to 1.3 mm, the ratio that best matched the standards was 1:2 belonging to LP3<sup>a</sup> ( $\Delta E = 0.72 \pm 0.08$ ) when compared with 1:1 of the LP4<sup>c</sup> ( $\Delta E = 1.70 \pm 0.14$ ). An increased thickness of veneering material, 1.60 and 2.00 mm adopted from LP5 to LP8 and the ratio 2:1 between Base Dentin and Transpa Dentin, resulted in a closer color correspondence. This trend was confirmed by LP6<sup>b</sup> ( $\Delta E = 1.08 \pm 0.04$ ) when compared with LP5<sup>e</sup> ( $\Delta E = 2.32 \pm 0.13$ ) and by LP8<sup>e</sup> ( $\Delta E = 2.52 \pm 0.04$ ) when compared with LP7<sup>f</sup> ( $\Delta E = 4.24 \pm 0.05$ ).

In order to achieve a certain shade, dental technicians usually follow the manufacturer's instructions. Such instructions by themselves are often insufficient to ensure the desired shade [21] and the findings of this paper may be useful in order to individually adjust the shade parameters. The human eye by itself cannot selectively evaluate the three parameters. For this reason, the use of clinical spectrophotometers, such as the Easyshade, that can give Delta information about the three parameters individually, can greatly help.

A limit of this study is represented by the choice of only one shade of veneering porcelain. Once the correct shade is selected, the greatest challenge is the reproduction of that shade with veneering ceramic facing the different thicknesses

that are clinically requested. Depending on the final thickness of the PFM restoration, the individual thickness of each layer and the ratio between the layers both play an important role in achieving the best color match, thus related to the optical behavior of the different layers of the ceramic system. Therefore it can be speculated that these results could be extended to other shades of the Vita VM13 system, but not to different porcelain systems. It could be interesting to test the behavior of other ceramic systems and to correlate the influence of each layer among different shades and brands.

Further studies might be useful in order to investigate: (i) whether the integration between the electronic information and the present layering data may result in a more accurate and easier shade match; and (ii) whether the technician can be guided regarding the degree of color change required to better match the intended shade of a ceramic restoration.

## 5. Conclusions

Within the limitations of this study and with the ceramic system analyzed, the thickness of each layer and the ratio between the different layers significantly influenced the final color of the PFM restorations. The ratio in thickness between Base Dentin and Transpa Dentin had a great impact on the final color. In relation to the final thickness of the veneering ceramic, an increase of Base Dentin caused a more Chromatic shade. Conversely, the predominance of Transpa Dentin reduced the Chroma of the color. An increase in the thickness of the Enamel layer resulted in a reduction of the Lightness (Value) and a decrease in the thickness of the Enamel layer increased the Lightness (Value).

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