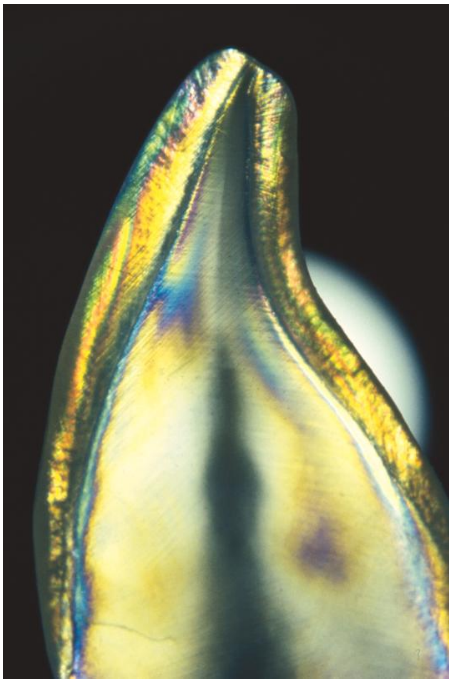
A STUDY OF DENTAL COLOR MATCHING, COLOR SELECTION AND COLOR REPRODUCTION



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CHAPTER 1

1.1 General Introduction

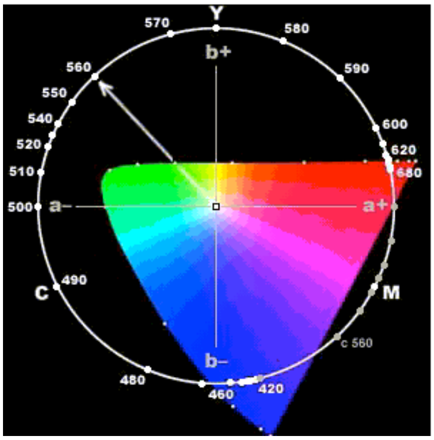
Accurate shade matching is one of the most challenging aspects of dental restorations and aesthetic dentistry. Due to the great variety of natural tooth color, achieving a close shade match of an artificial restoration with the natural dentition is a complex process. Practitioners require an understanding of color, light and related characteristics of porcelain and resin, as well as the ability to clearly communicate instructions with laboratory technicians. Successful shade matching integrates a number of critical factors, including an individual's perception of color, the light source in which shade is being determined (the practitioner's office), the color of the surrounding walls and cabinets, and the colors of patients' clothing and makeup. Practitioners must also take steps to reduce the problem of metamerism, a phenomenon in which the color of 2 objects look identical in one light source but look different under other light conditions (for example in sunlight versus fluorescent light).

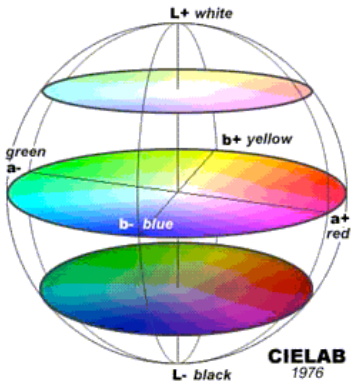
In order to obtain a natural looking restoration, there are two crucial steps in everyday dental practice: the selection of a color, through a shade guide, which will harmoniously integrate itself with the surrounding biological tissues and consequently the correct reproduction of this color in the prosthesis or restoration.

1.2 Color and science

Since Newton's experiments during the 18th century, color and science have tried to find a common field. But color is difficult to manage, as it is usually something that has been related more to art rather than to science. Color is almost indefinable, and even with dramatic improvements in scientific knowledge, a lot of work is still required. Dentistry is not away from this problem, and even if several attempts have been made to rationalize color match between natural teeth and restorative materials, shade selection is still one of the most empiric procedures in everyday practice. Many authors have tried in the past to address this issue, and the paper from Clark (1933), based mainly on the Munsell color scale of 1905, was the first attempt to organize dental colors.

In the same period, the Commission International de l'Eclairage (CIE, 1931) published the standards for color matching, establishing some scientific parameters for color evaluation. But the absence of valid scientific instruments for color measurement did not allow significant improvements. Sproull (1973; 1974) published a series of articles in which the three dimensional nature of color, and its relationship with dental shades was studied and a series of theoretical and practical indications were given in order to improve color matching in dentistry. These articles, that represented for a long time the "state of the art" for color matching, pointed out how the shade guides were poor and inadequate in relationship with the complexity of the appearance of the teeth. But while color dental applications seem to slow down for some time, the science of color did greatly improve. The desire was to use science express color and differences in color numerically. Since the Munsell system had an irregular space distribution, it was not possible to correlate two colors and to calculate the differences between them. In 1976 and 1978 the CIE developed a new system, called CIE Lab* (CIE, 1978), in which for the first time it was possible to express color in numbers, and calculate the differences between two colors using a formula that gives one number as value for color differences.





This so called “ΔE” value became critical in color science as well as in the color industry ranging from textiles to dentistry (Clarke, 1983)

$$\Delta E = [(L_1-L_2)^2 + (a_1-a_2)^2 + (b_1-b_2)^2]^{1/2}$$

Unfortunately, dental practice did not benefit immediately from this new knowledge to improve color matching; visual assessment was still considered the benchmark approach.

1.3 Shade guides

Tooth shade matching is most frequently performed visually using dental shade guides.

The first shade guide was introduced on the market in 1956 by Vita Zahnfabrik for the measurement of the color of ceramic systems. Although still imperfect, it introduced some visual parameters that with some minor modifications are still routinely used by dental practitioners. The Vitapan Classical Shade Guide consists of 16 tabs arranged into four groups based on hue and within the groups according to increasing chroma (also known as A-to-D arrangement) (Paravina, 2009). The most important issues are related to the need for and lack of a logical and adequate distribution in part of the color space encompassed by human teeth.

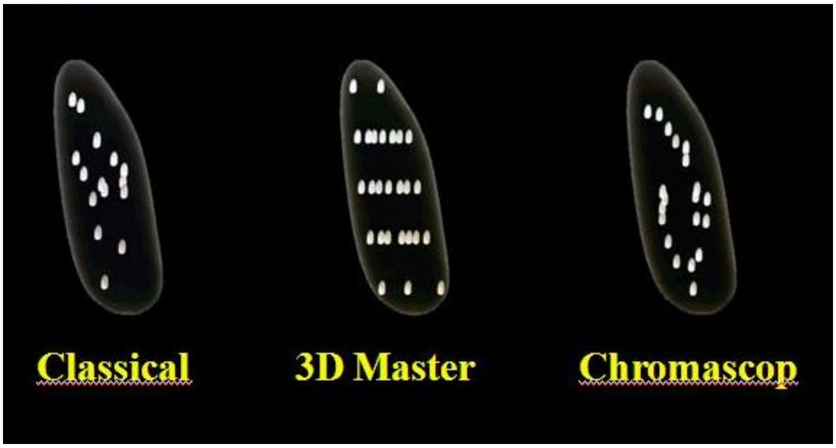
Another quite popular shade guide not systematically arranged is the Ivoclar-Vivadent Chromascop. As with the Vitapan Classical, the Chromascop is arranged in groups based on the hue (1=White, 2=Light Yellow, 3=Dark Yellow, 4= Grey and 5=Brown) and within the groups according to increasing chroma (from 10 to 40).

Dental color science then developed in a manner that minimized the errors in visual color selection (Miller, 1993 and 1994). In the late 1990s the Lab* system was adopted by dentistry and one of the first clinical results was the development of the Vita 3D Master Shade Guide.

The Vitapan 3D-Master color system consists of 11 sets of fired porcelain tooth-shaped samples built up with cervical, dentinal and incisal powders and composed of feldspar nepheline and high-temperature ceramic pigments from the Vita family of ceramic porcelains. The 11 sets consist of 26 samples ranging from lightest to darkest value, from lowest to highest intensity and from yellow to red. Samples are arranged in groups of two or three that form five sets (numbered 1 through 5). Each set represents a single value, 1 being the lightest tooth color and 5 the darkest. Chroma and hue are represented within each value set.

The distance between each of the pairs of adjacent colors is approximately 2 ΔE units. Each of the five lightness levels differs from the next by a ΔE of approximately 5. Each chroma level differs from the next by a ΔE of approximately 6. Hues are separated into middle, or M; yellow, or L; and red, or R (JADA, 2002).

The VITA 3D-Master Shade Guide is based on a color classification principle in which 3 dimensions of color, value (brightness), chroma (intensity of the color), and hue (the color itself), are considered equally so that the determination of shade can be easily carried out using systematic, consistent criteria (Paravina, 2009). The VITA 3D-Master Shade Guide addressed the most important elements of tooth shade measurement: a scientific color distribution, having a systematic arrangement of shades within the natural tooth color space and an objective, numerical measure of color, according to the colorimetric CIELab* order principle, rather than on the mere observation of the natural tissue aspects (Hammad, 2003), that can be written as a clear prescription for the laboratory technicians.



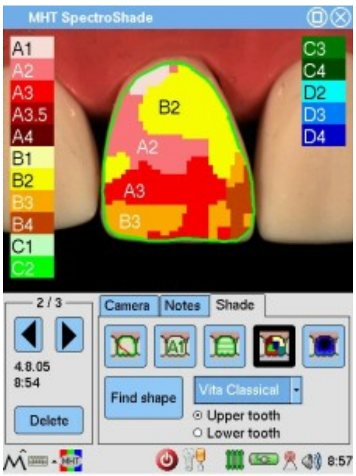
Recently, this guide was modified with the introduction of the sixth group (Number 0) for the shade matching of bleached teeth. A further development was the introduction of the Vita Linearguide 3D Master guide which adopted a linear approach to shade taking.

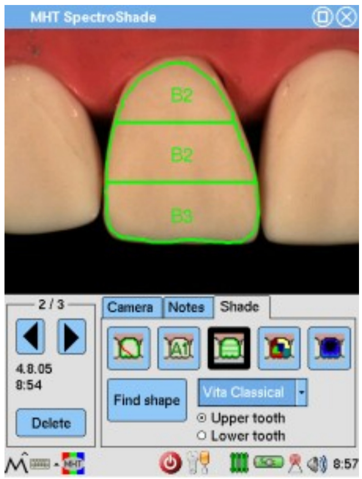
1.4 Shade taking devices: electronic aides

In order to minimize color mismatch due to visual estimation, two main categories of electronic instruments were developed for dental color analysis: colorimeters and spectrophotometers (Hunter, 1987). The Colorimeter is a relatively simple and low-cost instrument and it is designed to measure color on the basis of three axes or stimuli by using a filter that simulates the human eye. The spectrophotometer is a more sophisticated instrument, built to measure by reflection or transmission an observed object, giving the entire spectral curve and is limited for color measurement to the visible frequency range (usually 350-800nm). Significant advantages with spectrophotometric measurements include the ability to analyze the principal components of a series of spectra and the ability to convert spectrophotometric measures to various color measures. Although the first spectrophotometers were really accurate, they were quite complex instruments and difficult to manage and correctly calibrate. Moreover, spectrophotometers were bulky, with a large opening for measurements and expensive. For these reasons, their use was limited to the research laboratory. Colorimeters were portable, cheaper, with a smaller reading opening, but their lower accuracy and limitations resulted in the commercial failure of the Chromascan system in the past; the only dental colorimeter commercially produced at that time. Recent advances in electronics have resulted in more sophisticated CCDs. This has resulted in the development of electronic devices that are claimed to be able to measure the color of teeth. Such devices range from software that can be used in conjunction with images taken with a digital camera, to “pure” colorimeters and “pure” spectrophotometers, to the very latest development in which digital images are combined with a colorimeter or spectrophotometer.

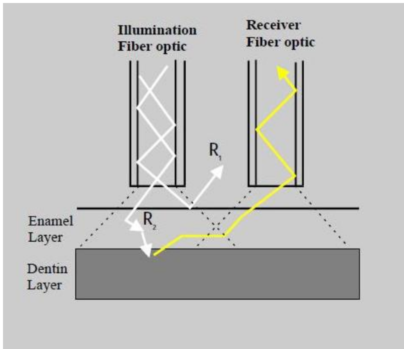
Shade Taking devices (from Brewer et al., 2004; Infodent 2007, modified)	
Instrument	**Type**
Shade Eye, Shofu	Colorimeter
Easyshade / Easyshade Compact, Vita	Spectrophotometer
Shade Scan, Cynovad	Digital color imaging / Colorimeter
Shade Vision, X-Rite	Digital color imaging / Colorimeter
Spectro Shade Micro, MHT	Digital color imaging / Spectrophotometer
Clear Match, Smart Technology	Software (requires a digital camera)
Color Scanner 2006, Nuova Franco Suisse	Software (requires a digital camera)
DVS11, DV	Spectrophotometer

Spectro Shade Micro (MHT), a combination of digital color imaging and spectrophotometer, may be considered one of the most sophisticated instruments. The advantages of these devices include the ability to acquire polarized images and use them for color analysis and calculation, comparison with several shade guides, coarse and fine color shade mapping, the ability to send data via e-mail to the lab, the ability to overlay the clinical image with the technician's work and several other features.





The Vita Easyshade is one of the latest spectrophotometers available for clinical use. The instrument's software is programmed to give absolute CIELab* color values only for natural teeth. Conversely, when assessing the color of a ceramic, the spectrophotometer provides the differences (Δ values) from color value presets in the instrument's database. The spectrophotometer data acquisition is different when reading natural tooth and ceramic also because the instrument applies different scanning methods on the two diversely structured substrates (JJL Technology, 2003). Ceramic restorations are generally less than 1.6mm in thickness and the color layers (dentin and opaque) are from 0.2–0.4 mm under the enamel porcelain layer. Conversely, inside the teeth, the dentin layer is generally 1.0–1.5 mm from the outer surface (Shillingburg et al., 1991). Furthermore, the enamel thickness causes a scattering of the penetrating light. Moreover, the overall thickness of a natural tooth is greater than that of a ceramic tooth.



In 2009 Vita Zahnfabrik introduced onto the market a new shade taking device, the Easyshade Compact, which represents an evolution of the previous one. Thanks to the use of LED technology,

the new device became smaller, wireless and easier to handle. The most important difference between the two devices is that the Compact has a single spectrophotometer rather than the two ones belonging to Easyshade standard. In the standard Easyshade the difference in color reading between natural teeth and ceramic restorations is due to two different spectrophotometers embedded in the instrument. In the Easyshade Compact's tip there are two different sets of LEDs that provide different light according to what is being measured and the reflected light converges in a single Charge Coupled Device (CCD).

The question to ask is how reliable these instruments are and if they are ready to be routinely used in the dental office. Very few scientific papers are available on this subject (Paul et al., 2002; Tung et al., 2002; Baltzer et al., 2005; Klemetti et al., 2006; Kim-Pusateri et al., 2007). However, it is necessary to underline that this different and innovative approach to shade selection has enormous educational potential. Both undergraduate and post-graduate students can benefit from these devices. These instruments allow an improved understanding of color perception and its correlation with clinical aspects as well as measuring difficult parameters such as Translucency, Hue, Chroma, and Value.

1.5 Shade reproduction

Once the correct shade has been selected, the second step is to reproduce this color in the restoration. Several studies demonstrated that the layering ratio between opaque and translucent shades greatly influences the final results of the restoration. Even a correct shade selection is not enough if it is not correlated with thickness and layering of the restoration (Omar et al., 2008).

Douglas et al. (2003) found that the ability to reproduce the color of the target shade tab differed among laboratories and most crowns fabricated by the laboratories in their study, when compared to the prescribed shade tab, were above the clinical threshold for an acceptable shade match ($\Delta E=3.7$). 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 (Ozturk et al., 2008), glazing (Yilmaz et al., 2008), the mixing ratio between powder and liquid (Zhang et al., 2004), different substructures (Kourtis et al., 2004) and layering (Dozic et al., 2003; Jarad et al., 2007). Dozic et al. (2003) 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. Jarad et al. (2007) 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). Wee et al. (2002) found that reliable delivery of a properly matched restoration to existing porcelain restorations cannot be ensured regardless of the shade assessment method used (visual or computer-generated).

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CHAPTER 2

2.1 Evaluation of measurement repeatability of clinical and laboratory spectrophotometers for color matching technique.

Gabriele. Corciolani, Alessandro Vichi. *International Dentistry South Africa 2006;8:62-70*.

Introduction

Correct shade selection and reproduction has been a continuous challenge for the clinician, as colour matching of teeth is complex, and shade selection errors can result (Ishikawa-Nagai et al., 1994).

The most common way to evaluate and reproduce natural teeth colour for ceramic restoration is visual comparison using dental shade guide tabs.

The first shade guide, introduced in 1929 by Vita, was developed according to the epidemiological distribution of natural tooth colour. The introduction of Vita Lumin Vacuum Shade Guide in 1956 was the first attempt to create a universal standard for teeth colour matching. Since then, several dental manufacturers have produced their own shade guides, producing a marked improvement in color reproduction for ceramic restoration (Wee et al., 2002), but at the same time generating a certain amount of confusion in clinicians.

Between 1976 and 1978 the “Commission Internationale de l’Enclairage” (CIE) developed a new system, called CIELab*, when for the first time it was possible to classify and correlate colour numerically, and to calculate the difference between two colours using a formula that gives one number (ΔE) as value for colour differences (Clarke et al., 1983).

In the late 1990's the CIELab* system was incorporated into dentistry and consequently, one of the first clinical advances was the development of the Vita 3D Master Shade Guide. This shade guide was not based merely on the observation of natural tooth colour, but on scientific findings and the systematic coverage of the tooth colour space of natural teeth, according to a systematic colorimetric CIELab* order principle (Hammad et al., 2003).

More recently, in order to minimize potential error in colour matching by personal estimation, research has endeavoured to use the science and theory of colour to devise a standard that will allow colours to be classified numerically, for easier and more precise transfer and communication of colour in restorative dentistry. This has been a significant step in the development of spectrophotometers (Baltzer et al., 2005; Douglas et al., 1997; Ishikawa-Nagai et al., 2005; Okubo et al., 1998; Paul et al., 2004; Tung et al., 2002).

The spectrophotometer is a sophisticated instrument, designed to measure an observed object by reflection or transmission, giving the entire spectral curve as result, limiting colour measurement to visible frequencies range (usually 350-800 nm).

The possibility to measure a colour numerically with a reliable digital instrument and to have a close correspondence with this number and the restorative material marks a new development in dentistry and spectrophotometers could become part of the routinely used office devices. To achieve this requires investigation into any doubt clinicians may have in the scanning repeatability and the reliability of these instruments.

The aim of this study was to establish whether there is repeatability in spectrophotometric measurement and to make a comparison between a clinical spectrophotometer and a laboratory one.

Materials and Methods

Two different types of spectrophotometers were used for this study: the VITA Easyshade (Vita Zahnfabrik, Bad Säckingen, Germany), a standalone clinical system and the PSD1000 (Ocean Optics, FL, USA) that is equipped with an integrating sphere (ISP-REF, Ocean Optics, FL, USA) with a 10mm aperture. The spectrophotometer PSD1000 was connected to a computer running measurement software (OOIBase 32, Ocean Optics, FL, USA).

In order to verify the reading repeatability of the two spectrophotometers tested, five ceramics disks were produced in different layering, with a fixed total thickness of the samples being maintained.

0,7 mm thick sample discs of 15mm in diameter of a self-curing acrylic resin material (DuraLay, LOT 052802, Reliance Dental Manufacturing Co., Worth, IL, USA) were made in a cylindrical mould.

After applying the material into the mould, a glass plate was pressed on the surface in order to obtain a flat surface. Great attention was given to avoid bubble formation.

When completely cured, the resin sample was extracted from the mold and put into a refractory cast filled with the refractory investment (GC Stellavest, GC Europe, Leuven, Belgium) and placed in a burnout furnace (Ovomat 7, Manfredi-SAED, Torino, Italy) using the wax elimination technique.

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

The disc-shaped specimens obtained were roughened using a sandblaster (Skylab, Tecnogaz, Parma, Italy) with AlO_2 particles of 100µm diameter.

Measurements were based on a single ceramic system (Vita Omega 900 Metallkeramik, Vita Zahnfabrik, Bad Säckingen, Germany). The colour selected was A3. A first wash opaque layer was used, as recommended by the manufacturer's instructions. After the application the opaque layer was fired in a ceramic oven (Programat X1, Ivoclar Vivadent, Schaan, Liechtenstein) according to the manufacturer's instructions. A second opaque layer was applied and fired.

Following manufacturer's instructions, the dentine layer was then stratified. A first opaque dentine layer (A3 Opaque Dentine 9033, Vita Zahnfabrik, Bad Säckingen, Germany) was applied in a thickness controlled by the regulated mold and fired following the manufacturer’s instructions after which a second dentine layer was stratified (A3 Dentine 9053, Vita Zahnfabrik, Bad Säckingen, Germany) and consequently fired.

Then, as indicated in the ceramic instructions, the enamel layer was stratified (EN2 Enamel 9072, LOT 7846, Vita Zahnfabrik, Bad Säckingen, Germany) and fired in the ceramic oven.

Finally, a glaze firing was performed according to the manufacturer’s instructions for each sample.

Each layer was measured by an electronic digital caliper (1651 DGT, Beta, Milan, Italy) with a 10μm resolution.

The variable thicknesses of the specimens are shown in table 1.

Table 1. Thickness of the specimens.

Sample	Alloy	Opaque	Opaque Dentin	Dentin	Enamel	Final
1	0,70 mm	0,15 mm	0,20 mm	0,45 mm	0,50 mm	1,30 mm
2	0,70 mm	0,15 mm	0,25 mm	0,60 mm	0,30 mm	1,30 mm
3	0,70 mm	0,15 mm	0,15 mm	0,30 mm	0,70 mm	1,30 mm
4	0,70 mm	0,15 mm	0,35 mm	0,70 mm	0,10 mm	1,30 mm
5	0,70 mm	0,15 mm	0,45 mm	0,50 mm	0,20 mm	1,30 mm

The colour evaluation of each sample was repeated 5 times with each spectrophotometer to verify the scanning repeatability.

The Vita Easyshade Dental Spectrophotometer consists of a base unit and a hand piece: the colour evaluation was repeated 5 times for each sample by fixing the handpiece of the device to a graduated stand and 5 times for each sample by free hand simulating clinical use. “Restoration” mode was selected using A3 shade as comparison.

The Ocean Optics Lab Spectrophotometer PSD 1000 consists of an integrating sphere, a base unit and integrating software. The samples were placed on the sphere aperture and the colour evaluation was repeated for 5 times for each sample.

The spectrophotometer repeatability was statistically evaluated by analyzing the Coefficient of Variation (CV), which represents the ratio of the standard deviation to the mean, of the CIELab* colour values. The software used was SPSS 12.0 (SPSS, Chicago, IL, USA).

Results

The results are shown in the tables 2, 3 and 4.

In table 2 and 3 the colour values obtained with Vita Easyshade are reported.

The first column indicates the scanning of each sample, where the sample is represented numerically and the letter represents the number of the scan. The values of the Delta related to Lightness, Chroma, Hue and ΔE, are reported in the other columns, a result of the comparative measurements made by the Easyshade. The column ΔE LC indicates the values of ΔE without taking into consideration the value of the Hue. The last column notes the instrument’s evaluation of the restoration.

Table 4 reports the colour values obtained with Ocean Optics PSD 1000.

The first column indicates the scanning of each sample, where the sample is represented numerically and the letter represents the number of the scanning. As the PSD 1000 gives absolute CIELab* values, the absolute values of colour evaluation are indicated in the other columns.

The values of CV ranged between 0 and 0,913, as shown in the Tables. These very low values demonstrated an excellent scanning repeatability for both the spectrophotometers tested.

Table 2. Vita Easyshade color evaluation (fixed to the stand).

Scanning	ΔE	ΔC	ΔH	ΔL	ΔE_{LC}	Value
1.a	5,1	-3,6	-2,7	3,5	5,0	Fair
1.b	5,1	-3,7	-2,7	3,5	5,1	Fair
1.c	5,2	-3,7	-2,7	3,6	5,2	Fair
1.d	5,3	-3,8	-2,7	3,6	5,2	Fair
1.e	5,3	-3,8	-2,7	3,6	5,2	Fair
$CV_{\#}$	0,019	0,023	0	0,015	0,017	
2.a	4,3	-2,6	-3,4	3,2	4,1	Adjust
2.b	4,3	-2,6	-3,4	3,2	4,1	Adjust
2.c	4,3	-2,6	-3,4	3,2	4,2	Adjust
2.d	4,3	-2,6	-3,4	3,2	4,1	Adjust
2.e	4,3	-2,6	-3,4	3,2	4,1	Adjust
$CV_{\#}$	0	0	0	0	0,011	
3.a	6,1	-4,9	-2,9	3,5	6,1	Fair
3.b	6,1	-5,0	-2,9	3,5	6,1	Fair
3.c	6,2	-5,0	-2,9	3,5	6,1	Fair
3.d	6,2	-5,0	-2,9	3,5	6,1	Fair
3.e	6,2	-5,0	-3,0	3,5	6,1	Fair
$CV_{\#}$	0,009	0,009	0,015	0	0	
4.a	2,4	0,1	-3,6	2,0	2,0	Good
4.b	2,4	0,1	-3,6	2,0	2,0	Good
4.c	2,4	0,1	-3,6	2,0	2,0	Good
4.d	2,4	0,1	-3,6	2,0	2,0	Good
4.e	2,4	0,1	-3,6	2,0	2,0	Good
$CV_{\#}$	0	0	0	0	0	
5.a	2,8	-1,1	-3,5	2,2	2,5	Good
5.b	2,7	-1,1	-3,5	2,2	2,5	Good
5.c	2,7	-1,1	-3,5	2,2	2,5	Good
5.d	2,7	-1,1	-3,5	2,2	2,5	Good
5.e	2,7	-1,1	-3,5	2,2	2,5	Good
$CV_{\#}$	0,016	0	0	0	0	

$_{\#}$ Coefficient of Variation

Table 3. Vita Easyshade color evaluation (hold by hand).

Scanning	ΔE	ΔC	ΔH	ΔL	ΔE_{LC}	Value
1.a	4,0	-2,6	-3,0	2,8	3,9	Adjust
1.b	3,9	-2,7	-3,1	2,7	3,9	Adjust
1.c	3,8	-2,5	-3,0	2,7	3,7	Adjust
1.d	3,9	-2,7	-3,1	2,7	3,8	Adjust
1.e	3,7	-2,5	-3,1	2,5	3,6	Adjust
$CV_{\#}$	0,0295	0,0385	0,0179	0,0409	0,0345	
2.a	3,2	-1,1	-3,7	2,7	2,9	Adjust
2.b	2,9	-1,1	-3,8	2,4	2,6	Good
2.c	3,1	-1,2	-3,7	2,6	2,9	Adjust
2.d	2,9	-1,1	-3,6	2,4	2,7	Good
2.e	3,1	-1,3	-3,8	2,5	2,8	Adjust
$CV_{\#}$	0,0441	0,0771	0,0225	0,0517	0,0469	
3.a	5,2	-4,1	-2,5	3,1	5,1	Fair
3.b	5,4	-4,2	-2,8	3,2	5,3	Fair
3.c	5,5	-4,4	-2,8	3,2	5,5	Fair
3.d	5,6	-4,6	-2,5	3,1	5,6	Fair
3.e	5,6	-4,6	-2,6	3,1	5,6	Fair
$CV_{\#}$	0,0306	0,0521	0,0574	0,0174	0,04	
4.a	2,9	0,1	-5,5	2,1	2,1	Good
4.b	2,9	0,1	-5,5	2,1	2,1	Good
4.c	2,8	0,0	-5,4	2,0	2,0	Good
4.d	2,9	0,0	-5,5	2,1	2,1	Good
4.e	2,9	0,1	-5,5	2,1	2,1	Good
$CV_{\#}$	0,0155	0,9129	0,0082	0,0215	0,0215	
5.a	3,0	-1,4	-3,7	2,3	2,7	Good
5.b	3,0	-1,4	-3,6	2,3	2,7	Good
5.c	2,7	-1,1	-3,6	2,1	2,4	Good
5.d	2,9	-1,4	-3,6	2,3	2,7	Good
5.e	2,9	-1,3	-3,6	2,3	2,6	Good
$CV_{\#}$	0,0422	0,0988	0,0124	0,0396	0,0498	

CV = Coefficient of Variation

Table 4. Ocean Optics PSD 1000 color evaluation.

Scanning	L*	a*	b*	Chroma	Hue	X	Y	Z
1.a	75,46	2,38	20,78	20,92	1,46	47,35	49,02	34,43
1.b	75,79	2,85	18,79	19,01	1,42	48,02	49,54	36,39
1.c	75,77	2,98	18,50	18,74	1,41	48,05	49,51	36,59
1.d	75,48	2,47	20,40	20,55	1,45	47,41	49,04	34,74
1.e	75,72	2,72	19,16	19,36	1,43	47,87	49,43	36,00
$CV_{\#}$	0,002	0,094	0,052	0,049	0,015	0,007	0,005	0,028
2.a	75,55	3,05	22,02	22,23	1,43	47,72	49,15	33,61
2.b	75,55	3,01	22,22	22,42	1,44	47,71	49,15	33,46
2.c	75,59	3,19	21,16	21,40	1,42	47,84	49,22	34,30
2.d	76,10	3,80	18,82	19,20	1,37	48,87	50,06	36,80
2.e	75,78	3,45	20,44	20,73	1,40	48,23	49,53	35,10
$CV_{\#}$	0,003	0,099	0,066	0,062	0,020	0,010	0,008	0,039
3.a	76,51	2,49	16,69	16,88	1,42	49,03	50,72	39,07
3.b	76,14	1,99	18,61	18,72	1,46	48,27	50,12	37,01
3.c	76,09	1,99	18,46	18,56	1,46	48,18	50,03	37,06
3.d	76,26	2,05	17,88	18,00	1,46	48,47	50,31	37,75
3.e	76,01	1,90	18,79	18,88	1,47	48,03	49,91	36,70
$CV_{\#}$	0,003	0,112	0,047	0,045	0,013	0,008	0,006	0,025
4.a	75,60	3,84	22,78	23,11	1,40	48,09	49,23	33,11
4.b	75,35	3,65	24,33	24,60	1,42	47,63	48,83	31,68
4.c	75,37	3,79	23,69	23,99	1,41	47,71	48,86	32,16
4.d	75,51	4,05	22,80	23,16	1,39	48,02	49,09	32,98
4.e	75,60	4,05	22,23	22,60	1,39	48,16	49,23	33,52
$CV_{\#}$	0,002	0,045	0,036	0,034	0,009	0,005	0,004	0,0229
5.a	75,49	3,62	20,25	20,57	1,39	47,83	49,05	34,86
5.b	75,74	3,69	19,68	20,02	1,39	48,25	49,46	35,64
5.c	75,94	4,05	17,80	18,26	1,35	48,69	49,78	37,37
5.d	76,41	4,42	16,27	16,86	1,31	49,58	50,56	39,28
5.e	75,64	3,73	19,55	19,91	1,38	48,11	49,30	35,60
$CV_{\#}$	0,005	0,085	0,089	0,080	0,025	0,014	0,019	0,049

CV = Coefficient of Variation

Discussion

In recent years, scientific study of dental colour has been directed towards minimizing errors in visual colour selection primarily through the use of two instruments: colorimeters and spectrophotometers (Hunter et al., 1987).

The colorimeter is a relatively simple and low-cost instrument designed to measure colour on the basis of three axis or stimuli by the way of filter that simulates the human eye. The spectrophotometer is a more sophisticated instrument, designed to measure an observed object by reflection or transmission, the results of which are the entire spectral curve, limiting colour measurement to a visible frequencies range (usually 350-800nm). The first spectrophotometers were expensive and cumbersome, with large aperture for measurement. With the evolution of optic fibre technology, dental manufacturers are now able to produce cost-effective spectrophotometers that are easy to operate, with a small aperture for measurement.

Because specular reflected light contains little or no colour information, the most important development was the ability to exclude all specular measurements. To obtain the proper degree of absorption and dispersion inside the tooth it is necessary to have light penetrating a tooth to the dentin level, travelling through the enamel, and then exiting some distance away. This is possible through fibre optic technology. Where there are two, parallel fiber optics, (transmitter and receiver), the only light that will enter the receiver fibre optic is the light reflected from the surface at the intersection of the two fiber optics' acceptance cone (JJL Technology, 2003).

The initial step in the evaluation of the clinical use of the Vita Easyshade dental spectrophotometer is to consider the reliability of the spectrophotometer. For this reason, the first phase was to evaluate the repeatability of the readings of the instrument, as a mandatory requirement to further evaluate the performances in comparison with the performance of the Ocean Optics PSD 1000 as an established lab instrument (Vichi et al., 2004).

The Ocean Optics PSD1000 is equipped with an integrating sphere which directs a light source over an object and collects almost all the reflected light from the object with a spherical cavity that is totally diffused and standardized white (Teralon). Easyshade's measurement technique utilizes large diameter fiber optics arranged in a specific pattern in a stainless steel probe, that are able to both illuminate a tooth and to receive light that is internally scattered by the enamel layer and reflected from the dentin layer of the tooth. Specific optic fibers transmit the light to the tooth (source fibers) and receive the light reflected from the tooth (receiver fibers), excluding all specular measurements (JJL Technology, 2003).

The reading values obtained from the tests have shown an excellent scanning repeatability, both for the clinical spectrophotometer (Easyshade) and for the laboratory one (PSD1000). In analyzing Table 4, it can be stated that very low values of coefficient of variation (0,002<CV<0,111) were obtained for the Ocean Optics

PSD1000 (the spectrophotometer gives a reading value as an average of 5 scanning). Considering Easyshade's reading values, it's possible to point out the good repeatability in repeated scanning, both by fixing the handpiece of the device to a graded stand ($0<CV<0{,}022$) and holding it by hand ($0{,}008<CV<0{,}913$). Analyzing sample n°1 and sample n°2 colour values, in both fixed and in hand free evaluation, Easyshade asses two different values of quality of the restoration, influenced by the values of ΔE ($\Delta E<3$=Good, $3<\Delta E<5$=Fair, $\Delta E>5$=Adjust). It may be tentatively assumed that these different quality evaluations for the same sample are due to the calibration process.

The ceramic colour evaluations performed with the clinical spectrophotometer (Easyshade) are not in absolute CIELab* values, but the instrument gives the measurements as a comparison with the colour values set in the spectrophotometer. Easyshade is not programmed to measure ceramic restorations giving absolute values. The instrument's software is programmed to obtain absolute colour values only for natural teeth. These two scanning methods are different because the instrument takes into consideration the two different structures analyzed: ceramic restorations are generally less than 1.5mm in thickness and the colour layers (dentin and opaque) are from 0.2 - 0.4mm under the enamel porcelain layer. With teeth, the dentin layer is generally 1.0 - 1.5mm from the outer surface. The enamel thickness is a layer that causes a scattering of the penetrating light ray: the higher thickness of a natural tooth as opposed to a ceramic tooth explains the difference between the two scanning systems.

The differences in manufacture do not allow a direct comparison to be made between the two tested instruments, because the absolute CIELab* values set in the Easyshade for each colour are not supplied by the manufacturer and a pure A3 colour sample to measure with Ocean Optics PSD1000 was not available.

Conclusions

Through analysis of the observations in this study and within the limits of the test used, some conclusions can be drawn.

1) Even though a direct comparison of the lab and of the dental spectrophotometer was not possible because of the difference in engineering, the repeatability of the clinical instrument was comparable to the lab instrument.
2) The high repeatability of readings of the clinical instrument is an initial important result in the evaluation of this instrument. Further studies are in progress to evaluate different features of this instrument that have the potential to simplify shade selection as a critical step in everyday dental practice.

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CHAPTER 3

3.1 Spectrophotometric evaluation of color match to VITA classical shade guide of four different veneering porcelain systems for metal ceramic restorations.

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Introduction

Color matching of a ceramic restoration to natural dentition remains a key factor in achieving optimal esthetic results in prosthetic dentistry. In clinical practice the color matching task is accomplished by the shade selection process, which starts by using a visual assessment or instrumental color analysis. Visual shade selection is the most common method of color determination. Several shade guides have been proposed by the manufacturers and by far the most used worldwide is the Vitapan classical. Once the target shade map is determined the laboratory should replicate this color by mean of a porcelain system that usually is correlated to the selected shade guide.

The factors that have an influence on final color of dental porcelain include porcelain brand and batch, firing conditions, condensation technique, modeling liquid, substrate and porcelain thickness. The manipulative variables of firing temperatures and condensation, as well as the choice of modeling liquid were found in a previous study (Rosenstiel et al., 1988) to have little influence on the final color of the restoration. The number of firings however is a potential source of color variations as documented,(Rosenstiel et al., 1988; Barghi et al., 1982; Barghi et al., 1977; Barghi et al., 1978, Ecker et al., 1985; Jorgenson et al., 1979; O'Brien et al., 1991) but if the number of firings is limited to five, the effect is negligible (Barghi et al., 1982).

Batch to batch variations were found to have a moderate influence on color (O'Brien et al., 1991; Barghi et al., 1985). The substrate, meaning the alloy type of the metal ceramic restoration, is a potential source of color variation (Brewer et al., 1985; Jacobs et al., 1987; O'Neal et al., 1987; Seghi et al., 1986; Terada et al., 1989; Woolsey et al., 1984; Crispin et al., 1991). An important source of variability of the color is the porcelain thickness as previously reported (Jorgenson et al., 1979; Jacobs et al., 1987; Terada et al., 1989; Terada et al., 1989; Douglas et al., 1999).

Preston et al. (1985) identified as one of the major limits of the current shade-guide systems the fact that porcelains do not match the shade guides. Wide variations of color according to the porcelain brand have been documented (Rosenstiel et al., 1988; O'Brien et al., 1991; Seghi et al., 1986; Groh et al., 1992). Customized shade tabs have been advocated to minimize this problem but so far the dental community has not embraced this procedure (Miller et al., 1987).

An additional difficulty of predicting the final color is represented by the need of having different layers of porcelain such as opaque, dentin and enamel (O'Brien et al., 1994; O'Brien et al., 1985).

It is accepted that the opaque layer should be as thin as possible to mask the metal substructure and usually appears to be 0.10–0.15 mm (Chiche et al., 1994). In addition, the amount of translucent porcelain necessary to reproduce the color of the target shade should be at least 1.0 mm.(Jacobs et al., 1987; Seghi et al., 1986; Chiche et al., 1994; McLean et al., 1979). Very limited information is available from the manufacturers or from the literature, on what the ideal proportion of dentin and enamel should be.

This study evaluated, by a spectrophotometric analysis, the variations in color between four dental porcelain systems and the target shades “A2, A3 and A3.5” of the shade guide Vitapan classical. The null hypothesis was that all porcelain systems would be able to clinically match the intended shade achieving $\Delta E \leq 3.7$.

Materials and Methods

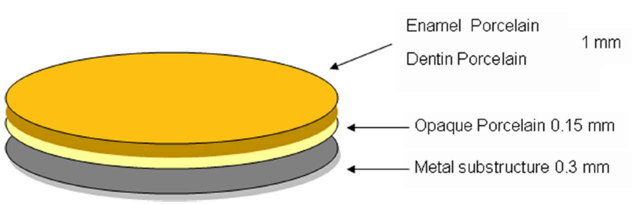
In order to make an appropriate use of the porcelain systems, instructions regarding the proper layering were retrieved from the manufacturers’ documentation of the porcelain systems. All the information available consisted of diagrams where the thickness of the different layers of opaque, dentin and enamel were calculated. The measures were calculated at 45% of the length of a central incisor starting from the incisal margin. Values were displayed in percentage and were used in the construction of the samples (Table 1).

Table 1. Porcelain systems selected for the study.

Porcelain system	Porcelain layer
Duceram Kiss	Opaque Dentin
	Incisal
Ivoclar IPS d.SIGN	Opaque Dentin
	Incisal
Vita Omega 900	Opaque, Opaque dentin, Dentin
	Incisal
Wieland Reflex	Opaque Dentin
	Incisal

In order to simulate metal ceramic restorations, disk-shaped specimens were preferred to tooth-shaped specimens previously employed (Groh et al., 1992). Disk-shaped specimens allowed a better control of the thickness of different layers and a flat surface was preferred in order to allow a more precise use of the spectrophotometer and obtain repeatable color measures (Seghi et al., 1989; Wee et al., 2000; Kourtis et al., 2004). A diagram of the samples is presented in Fig. 1.

Fig. 1. Scheme of stratification of disk-shaped specimens.



A porcelain substrate was selected (Cr-Co alloy - Heraenium P, Heraeus Kulzer, Dormagen, Germany). Metal disks 15 mm in diameter and 0.3 mm thick were fabricated using a cylindrical custom made steel mold (Fig. 2).

Fig. 2. Custom made cylindrical device.

The device also allowed having a mold 15 mm in diameter where height could be adjusted and acted as a guide to produce calibrated layers. The cast metal specimens were adjusted with stones, airborne-particle abraded with 50 µm aluminum oxide, cleaned with steam, and then oxidized according to the manufacturer guidelines.

Three different shades (A2, A3, A3.5) for four different ceramic systems were object of the present investigation. Ceramic systems were VITA Omega 900 (Vita Zahnfabrik, Bäd Sackingen,Germany), Duceram Kiss (DeguDent, Hanau, Germany), Wieland Reflex (Wieland Dental, Pforzheim, Germany) and Ivoclar IPS d.SIGN (Ivoclar Vivadent AG, Schaan, Liechtenstein) obtaining a total of 12 combinations. For each group, three samples were fabricated for a total of 36 specimens (Table 1). The metal specimen was inserted in the device and the same device was used in order to obtain calibrated layers of porcelain. A layer of 0.1 mm of porcelain opaque was first applied. Translucent porcelain, dentin and enamel were layered in the same manner according to the values obtained by the manufacturer diagrams as previously calculated (Table 2).

Porcelain system	Dentin porcelain	Enamel porcelain
VITA Omega 900	10% opaque dentin + 80% dentin	10%
Duceram Kiss	80%	20%
Wieland Reflex	80%	20%
Ivoclar IPS d.SIGN	50%	50%

Table 2. Percentages of dentin and enamel translucent porcelain calculated at 45% of the length of a central incisor starting from the incisal margin.

The total amount of translucent porcelain was 1 mm in thickness. The use of 1.0 mm thickness is representative of the usual clinical conditions and has been accepted for porcelain translucency (Brodbelt et al., 1980).

The layer thickness was evaluated after each firing and the necessary corrections were made by either grinding or adding porcelain. A digital caliper (1651 DGT, Beta, Milan, Italy) with a 10 µm resolution was used for all the measurements.

Condensation procedures were executed manually in the same manner as routine laboratory work. All the specimens were fabricated by the same operator. The porcelains were fired according to the manufacturer's recommendations.

In VITA Omega 900 specimens, a 0.1 mm layer of opaque dentin was applied in addition to translucent dentin and enamel as recommended by the manufacturer. However, the total thickness of the porcelain was equal to 1.0 mm as were the other specimens. All the specimens were subjected to four firings. No glazing cycle was performed. The porcelain surface was not polished because the adopted spectrophotometer is designed to avoid the influence of specular reflection, so glazing and polishing do not interfere with the measurements (JJL Technology, 2003).

Color of dental materials is expressed in “L*”, “a*” and “b*” coordinates according to the CIELab* color space. “L*” value represents the brightness, “a*” value represents the redness or greeness and “b*” value represents the yellowness or blueness.

The color difference of two objects can be calculated comparing the differences between respective coordinates applying the formula proposed by Clarke (1983):

$$\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$$

In the present study the threshold value of $\Delta E \leq 3.7$ for a clinical color match was adopted as suggested in the literature (Johnston et al., 1989).

Color measurements were made by a clinical spectrophotometer Easyshade (Fig. 3). The instrument has already stored the data for the Vitapan Classical shade guide. The instrument utilizes a 20 Watt halogen stabilized tungsten filament lamp. The Easyshade probe contains multiple receiver fiber optics spaced at different distances from the light source, coupled to two spectrometers, which varies the effective depth of the color measurement within a tooth or ceramic restoration. As a result, the path lengths of the light rays are different for the two spectrometers. The spectral resolution is 25 nm over the visible light range from 400 nm to 700 nm. The spectrophotometer makes up to 50 measurements per second (JJL Technology, 2003).

Fig. 3. Clinical spectrophotometer VITA Easyshade.

Corciolani et al. (2006) previously assessed the repeatability of color reading ability of the Vita Easyshade and as suggested the instrument was secured to a stand in order to have a repeatable position for the readings. Five readings were made for every sample and a mean was calculated.

Delta E values, calculated by the spectrophotometer according to the formula proposed by Clarke (1983) were statistically analyzed. The normality of the distribution in the groups was preliminarily checked using the Kolmogorv-Smirnov test. Two one-way ANOVA tests were applied assuming first the values of ΔE as the dependent variable and the shade selected as factor and then the values of ΔE as the dependent variable and the ceramic system selected as factor. The level of significance was set at $P < 0.05$. Tukey HSD test was applied for post-hoc comparison where needed.

Results

The values recorded by the spectrophotometer are reported in Table 3.

Ceramic	Omega 900			Duceram Kiss			Ivoclar dSIGN			Wieland		
Shade	A2	A3	A3.5	A2	A3	A3.5	A2	A3	A3.5	A2	A3	A3.5
ΔE Values	2.9	3.9	2.0	2.0	3.4	4.2	3.5	3.7	4.7	1.2	3.9	4.9
	3.4	4.2	2.1	2.4	3.6	4.3	3.5	3.9	4.7	1.4	4.2	5.0
	2.9	3.9	2.0	2.0	3.5	4.0	3.2	3.5	4.6	1.6	4.4	4.8

Table 3. Delta E values recorded by the spectrophotometer.

Values of ΔE ranged between 1.2 and 5.0. Shade clinical matching (ΔE ≤ 3.7) was recorded for shade A2 in all the ceramic systems, for shade A3 in Duceram Kiss and Ivoclar IPS specimens and for shade A3.5 only in Vita Omega 900 specimens. All the other specimens failed to achieve shade matching.

The means of ΔE values calculated for the ceramic system and for the shade are shown in Table 4. The means for the four ceramic systems were 3.03; 3.27; 3.92 and 3.49 regardless of the shades. VITA Omega 900 obtained the best average shade matching.

Ceramic system	Shade			
	A2	A3	A3,5	Mean
VITAOmega 900	3.07	4.00	2.03	3.03
Duceram Kiss	2.13	3.50	4.17	3.27
Ivoclar	3.40	3.70	4.67	3.92
Wieland Reflex	1.40	4.17	4.90	3.49
Mean	2.50	3.84	3.94	
Significance	a	b	b	

Table 4. Means of ΔE values horizontally according to the ceramic system andvertically according to the shade.

However ANOVA analysis showed no statistically significant differences ($P > 0.05$) between the porcelain brands.

One-way ANOVA showed that the ceramic shade significantly influenced the ΔE values ($P < 0.05$). Post-hoc comparison among the ceramic shades further revealed that values of ΔE of A2[a] shade were comparable and significantly better if compared to shades A3[b] and A3.5[b].

Discussion

This study compared the color differences of fired porcelain compared to the shade guide Vitapan Classical. The stratification of the porcelain was executed in accordance to the diagrams retrieved by the manufacturers' instructions for a central incisors calculated at 45% of the length of a central incisor starting from the incisal margin. For this study was decided to use flat disk shaped specimens in order to provide uniform thicknesses of the ceramic layers. Tooth shaped specimens, employed in other studies (Groh et al., 1992), allow light reflection similar to clinical conditions, but hardly allow uniform thicknesses of porcelain. It is well documented in the literature that thickness of porcelain is one of the main sources of shade mismatch (Jorgenson et al., 1979; Jacobs et al., 1987; Terada et al., 1989; Terada et al., 1989; Douglas et al., 1999). In the present study a uniform thickness of 1.0mm was obtained for all the specimens. The use of a set thickness allows for a defined condition under which the color differences can be quantified and porcelain brands can be compared.

The use of 1.0mm thickness is representative of the usual clinical conditions and has been accepted for porcelain translucency (Brodbelt et al., 1980).

Several studies (Johnston et al., 1989; Seghi et al., 1989; Ruyter et al., 1987; Ragain et al., 2001; Vichi et al., 2004) provide information regarding clinical color-matching tolerance. Vichi et al. (2004) reported value of $\Delta E < 1$ as not appreciable by human eye. Johnston et al. (1989) determined clinically acceptable shade matching in oral conditions for ΔE up to 3.7.

For shade A2 all the porcelain brands showed values of ΔE below or equal to 3.7 and therefore clinically acceptable. This result was also confirmed by one-way ANOVA test, where a statistically significant difference was found ($p<0.05$). Post-hoc test assessed a closest color correspondence with standards for A2[a] shade rather than A3[b] and A3.5[b] shades.(Table 4)

Therefore, the null hypothesis must be rejected because only specimens in A2 shade for all ceramic systems, in A3 shade for Duceram Kiss and Ivoclar IPS and in A3.5 shade for Vita Omega 900 have been able to clinically match the intended shade achieving $\Delta E \leq 3.7$, while all the other specimens failed to achieve shade matching.

The use of a layered porcelain (opaque, body and incisal) was preferred because similar to the clinical condition. In a previous study (O'Brien et al., 1994; O'Brien et al., 1985) double layer porcelain was found to produce differences in color when compared to single layers samples. Different porcelain systems seem to require different proportions in terms of thickness of porcelain layers. Such variation in adjunct to variation of powders contents is a great source of color variation.

One of the limitations of this type of investigations is due to the limited information available from the manufacturers regarding the amount of opaque, body and incisal porcelain necessary to obtain the desiderate shade. In the present study the stratification was based on the diagrams retrieved from the manufacturers' instructions, but it is unknown what the degree of accuracy of such diagrams is.

Future investigations should be addressed to other shades (B, C, and D) of the VITA scale and to establish if varying the percentage of incisal and body translucent porcelain better shade matching can be achieved. The role in shade matching of opaque modifiers and opaque dentin should also be clarified.

According to the results of the present investigation, it may be concluded that the indications given from the manufacturer to help the technician to obtain the color match between the selected shade and the final restoration are very limited, and not sufficient to avoid color mismatch. Even if the right color selection is made, the fabrication of restoration of the aimed color is still a non completely predictable procedure.

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CHAPTER 4

4.1 Colour correspondence of a ceramic system in two different shade guides.

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Introduction

The standard clinical procedure to select and reproduce natural teeth colour with ceramic restoration is the visual comparison using a dental shade guide. The first shade guide, introduced in 1929 by Vita, was structured according to an epidemiological distribution of teeth colour observed in nature. The introduction in 1956 of Vita Lumin Vacuum Shade Guide represented a milestone in the development of a universal standard for tooth colour reference. Notwithstanding its wide clinical success, this shade guide is still based on appearance rather than on a scientific basis. Scientific was instead the approach for the development in 1998 of the Vita 3DMaster shade guide, referenced to Lab* system established in 1976 by the Commision Internationale du l’Eclairage, which provides the international scientific standards for colour measurements. In other words, the Vita 3D-Master is founded on a scientific colour distribution, having a systematic coverage of the tooth colour space of natural teeth according to the colourimetric CIELab* order principle, rather than on the mere observation of the natural tissue aspects (Hammad et al., 2003).

Although the use of such a shade guide can be considered an advancement, in practice colour selection is still carried performed by visually comparing shade tabs with the tooth.

With the objective of minimizing colour mismatch due to visual estimation, clinical dental spectrophotometers have been developed and marketed. Such instruments are based on CIELab* colour system, although they provide measurements in any dental shade system. Their technology allow to convert perception in numbers, thus making colour selection and colour communication in dentistry easier and more reliable (Corciolani et al., 2006; Baltzer et al., 2005; Dougas et al., 1997; Ishikawa-Nagai et al., 2005; Okubo et al., 1998; Paul et al., 2002; Paul et al., 2004; Tung et al., 2002).

Although clinical spectrophotometers are still under evaluation, they have so far provided satisfactory results and have the potential to greatly simplify the first step in the colour matching procedure, i.e. colour selection.

Nevertheless, the following step in the procedure, colour reproduction, still requires attention and possibly a more scientific approach. In this perspective, it would seem useful if also restorative systems could be based on the CIELab* colour space, as the 3D Master shade guide and clinical spectrophotometers are.

Vita Omega 900 is currently the only dental ceramic system marketed in Vitapan Classical shade guide as well as in Vitapan 3D

Master. For this reason Vita Omega 900 was the object of this study, which was aimed at testing, by means of a clinical spectrophotometer, the ability of the mentioned ceramic system to correctly reproduce the selected shade colour with reference to the Vitapan Classical and 3D Master shade guides.

The formulated null hypothesis was that no significant difference existed between selected colour and restoration colour for the two shade guides.

Materials and Methods

The stand-alone clinical spectrophotometer VITA Easyshade (Vita Zahnfabrik, Bad Säckingen, Germany) was used to measure colour differences in the ceramic system Vita Omega 900 Metallkeramik (Vita Zahnfabrik).

Fifteen ceramics discs were fabricated with different layering patterns for each shade, keeping constant the specimen total thickness.

Self-curing acrylic resin discs (DuraLay, LOT 052802, Reliance Dental Manufacturing Co., Worth, IL, USA), 0,7 mm in thickness and 15 mm in diameter were made in a cylindrical stainless steel mold. After applying the material into the mold, a glass plate was pressed onto the most superficial layer in order to obtain a flat surface. Great attention was given to avoid bubble formation within the resin.

Once completely cured, the resin sample was extracted from the mold, put in a refractory cast filled with investment (GC Stellavest, GC Europe, Leuven, Belgium), to be placed in a burnout furnace (Ovomat 7, Manfredi-SAED, Torino, Italy), following the wax elimination technique.

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, Italy). The obtained disc-shaped specimens were roughened with a sandblaster (Skylab, Tecnogaz, Parma, Italy), using AlO_2 particles of 100 μm diameter.

For ceramic layering, A3 shade for Vitapan Classical and 2M3 shade for Vitapan 3D-Master were selected for being the most frequently re-assorted shade in each system according to the manufacturer. Following manufacturer's instructions, a wash opaque layer (A3 Opaque 9003/2M3 Opaque 9307, Vita Zahnfabrik) was applied first and fired in a ceramic oven (Vacumat 500, Vita Zahnfabrik). Then, a second opaque layer was added and fired (OP2 Opaque Paste 352, Vita Zahnfabrik). At this stage the first opaque dentine layer (A3 Opaque Dentine 9033/2M3 Opaque Dentine 9033, Vita Zahnfabrik) was applied in a thickness controlled by the regulated mould, and fired following the firing manufacturer instructions. Then, a second dentine layer was stratified (A3 Dentine 9053/2M3 Dentine 9053, Vita Zahnfabrik), and consequently fired. Subsequently, as indicated in ceramic instructions, the enamel layer was stratified (EN2 Enamel 9072, LOT 7846, Vita Zahnfabrik), and fired in the ceramic oven. At the end, for each sample, a glaze firing was done according to the ceramic manufacturer's instructions. Each layer was measured by an electronic calliper (1651 DGT, Beta, Milan, Italy) with a 10 μm resolution. Three distinct layering patterns were realized that differed for the thickness of the opaque dentin, dentin, and enamel layers (Table 1).

Table 1. Layering patterns of the ceramic specimens

Sample		LP	Alloy	Opaque	Opaque Dentin	Dentin	Enamel	Final
O900 Cl	O900 3D							
1-5	16-20	1	0,30mm	0,15mm	0,25 mm	0,60mm	0,30mm	1,30mm
6-10	21-25	2	0,30mm	0,15mm	0,35 mm	0,70mm	0,10mm	1,30mm
11-15	26-30	3	0,30mm	0,15mm	0,45 mm	0,50mm	0,20mm	1,30mm

Spectrophotometric measurements

The spectrophotometer Vita Easyshade is composed by a base unit and a hand piece. The colour evaluation was done free hand simulating the clinical use. "Restoration" mode was selected using A3 and 2M3 shade as comparison.

Statistical analysis

Delta E values calculated by the spectrophotometer according to the formula proposed by Clarke (1983) were statistically analyzed. Having preliminarily checked for normality of data distribution (Kolmogorov-Smirnov test) and homogeneity of group variances (Levene test), the Two-Way Analysis of Variance was applied with Delta E values as the dependent variable, shade guide-ceramic system and layering pattern as factors. The Tukey test was applied for post-hoc comparisons as needed. In all the analyses the level of significance was set at p<0,05.

Results

The Two-Way ANOVA showed that both “shade guide-ceramic system” and “layering pattern” significantly influenced the Delta E values (p<0,001). Particularly, regardless of the layering pattern, the Delta E values of Vita Omega 900 in 3D Master shade guide were significantly lower than those of Vita Omega 900 in Vitapan Classical shade guide (Table 2).

Table 2. Descriptive statistics of the ΔE values recorded in the experimental groups. In the significance column, different superscript letters label significant differences when the ceramic system*layering pattern interactions were assessed at the univariate level.

Ceramic System	LP	n of specimens	Mean (ΔE)	SD	Significance (p<0.001)
Omega 900 Classical	1	5	3,04	0,46	d
	2	5	2,88	0,48	d
	3	5	2,9	0,46	d
Omega 900 3D Master	1	5	2,3	0,47	c
	2	5	1,76	0,49	b
	3	5	1,34	0,47	a

The three assessed layering patterns differed significantly among each other, according to the Tukey test for post-hoc comparisons. With regard to the significant between-factor interactions, when evaluated at the univariate level they disclosed a similarity in Delta E values for all the layering patterns with Vitapan

Classical. Conversely, with Vitapan 3D Master, the Delta E values were lower for the layering pattern 1 than for the 2, whose Delta E values were in turn lower than those of pattern 3 (Table 2). These differences were statistically significant according to the Tukey test for pairwise comparisons.

Discussion

Colour matching has always been a basic and primary step in prosthetic and restorative dentistry. Colour is one of the characteristics of a dental restoration that the patient evaluates first. Therefore, colour selection and reproduction represent a challenge to the clinician (Douglas et al., 1998).

Vitapan Classical has been considered for many years the reference shade guide among those available for ceramic systems. This role is going to be progressively taken over by Vitapan 3D-Master, a relatively new concept of systematic coverage of natural teeth colour space, based on the colourimetric CIELab* order principle (Hammad et al., 2003).

In this study, in order to verify whether with this new shade guide the match between tab standards and layered specimen is influenced by the shade guide, specimens made with the only one ceramic system available for use in both shade systems, Vita Omega 900, were compared. Ceramic specimens were prepared according to manufacturer’s layering instructions in a standardized 1,3 mm thickness over 0,3 mm thick metal substructure. Clinically, in the tooth preparations for porcelain fused to metal (PFM) restorations, tooth reduction may range between a minimum of 1,2 mm at the cervical third and 1,6 mm at the middle third. At the latter level, 1,2-1,3 mm represents the thickness of opaque and veneering, whereas 0,3-0,4 mm is the thickness required for the metal substructure. In the occlusal or incisal third the amount of tooth structure to be removed is at least 2,0 mm.

In recent years the scientific study of dental colour has been directed towards minimizing errors in visual colour selection through the use of spectrophotometers (Paul et al., 2002; Paul et al., 2004; Wee et al., 2002).

The Vita Easyshade is one of the latest spectrophotometer available for clinical use. In this study the instrument was used with a ceramic system belonging to the same manufacturer (Corciolani et al., 2006).

The instrument's software is programmed to give absolute CIELab* colour values only for natural teeth. Conversely, when assessing the colour of a ceramic, the spectrophotometer provides the differences (Delta values) from colour values presets in the instruments database. The spectrophotometer data acquisition is different when reading natural tooth and ceramic also because the instrument applies different scanning methods on the two diversely structured substrates. Ceramic restorations are generally less than 1,6 mm in thickness and the colour layers (dentin and opaque) are from 0,2–0,4 mm under the enamel porcelain layer. Conversely, inside the teeth, the dentin layer is generally 1,0-1,5 mm from the outer surface. Furthermore, the enamel thickness causes a scattering of the penetrating light. Moreover, the overall thickness of a natural tooth is greater than that of a ceramic tooth (JJL Technology., 2003).

With regard to ceramic assessment, it should be pointed out that the referential colour values in the instrument database can be considered reliable for colour matching because the ceramic systems object of this study and the clinical spectrophotometer used for colour measurements are produced by the same manufacturer.

When assessing the influence of the shade guide by comparing equally layered specimens of Vita Omega 900 in A3 and 2M3 shades, it was evident that the latter exhibited a closer colour correspondence with the colour values set in the spectrophotometer. This result may be explained by the ability of Easyshade to better match colours that are organized in a scientifically-based systematic spatial distribution. This colour distribution is the basis of the 3D Master shade guide (Bayindir et al., 2007; Paravina et al., 2002). As a matter of fact, Omega 900 in 2M3 shade demonstrated a significantly closer colour correspondence than Omega 900 in A3 shade (Table 2). Such a finding leads to rejection of the null hypothesis.

Data in Table 2 demonstrate that the closest colour correspondence with standards was obtained when, regardless of the ceramic system, the n°3 layering pattern was followed. In this pattern equal thicknesses of Opaque Dentine (0,45 mm) and Dentine (0,50 mm) were stratified.

The statistical analysis revealed a significant influence of the layering pattern on colour correspondence (Table 2). It should therefore be of scientific and clinical interest to assess with further research to what extent each layer influences the final colour.

The finding of a closer colour correspondence when referring to 3D Master also suggests the use of ceramic systems based on this shade guide in combination with the clinical spectrophotometer, for the purpose of minimizing errors in the colour matching procedures.

Conclusion

Within the limitation of this study, specimens of Vita Omega 900 in Vitapan 3DMaster shade guide exhibited for the investigated shade a closer match in colour than specimens of the same ceramic system in Vitapan Classical shade guide. Therefore, the higher colour correspondence can be considered to be shade guide dependant. Further studies are necessary in order to establish the influence of each layer on the final colour of the restorations.

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4.2 Color correspondence of two different ceramic systems in one shade guide

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INTRODUCTION

Dental porcelain, considering wear resistance, strength, toughness and good esthetics, is one of the materials most used to replace natural tooth tissue (Kelly et al., 1996). However dental porcelain does have limitations due to its numerous manipulative variables such as mixing of a powder with a liquid, layering schemes, firing procedures. For these reasons, the aimed shade is not easy to obtain, thus esthetic excellence is not always achievable. Conrad et al. (2007) in a systematic review of the literature reported that several all-ceramic materials and systems are currently available for clinical use, and that there is not a single universal material or system for all clinical situations. A successful restoration is dependent upon several variables including the skill of the clinician, the inherent properties of the material used and the limitations of the manufacturing process.

The esthetic demands of both patients and clinicians have resulted in the widespread use of porcelain and with its ability to match the color of natural teeth it is often the material of choice. However, clinical studies (Milleding et al., 1998; Bergman et al., 1999; Sjögren et al., 1998; Wee et al., 2002) have shown that the final color match of porcelain restorations relative to the adjacent natural dentition remains a challenge.

Tooth color is a combination of the color of the dentin, a relatively thick, opaque, chroma rich layer and the color of enamel, a relatively thinner, translucent, quite achromatic layer. These fundamental layering aspects of tooth color and appearance should ideally be replicated with porcelain. There is an additional esthetic challenge posed with metal ceramic restorations, where a natural appearance must be achieved with significantly thinner layers. The different layers of a natural tooth provide varying diffuse reflectance and there is a relationship between translucency and thickness of the layers. The color and reflectance of the inner layers poses a challenge to the clinician aiming to a good esthetic result (O'Brien, 2008). Dozic et al. (2003) in an in vitro study reported that small changes in thickness and shade of opaque and translucent porcelain layers can influence the final shade of the layered all ceramic specimens. Several other factors are relevant in influencing the final color of porcelain restorations, such as firing (Ozturk et al., 2008), glazing (Yilmaz et al., 2008), the mixing ratio between powder and liquid (Zhang et al., 2004), different metal frameworks (Kourtis et al., 2004).

The color selection procedure has also been the subject of several investigations (Wee et al., 2002; Clarke, 1983; Hammad, 2003; Baltzer et al., 2005; Douglas, 1997). It is not a scientifically based procedure and therefore it may be considered one of the weakest links in achieving the best possible esthetic result. The introduction of the Vita 3D Master shade guide (Vita Zahnfabrik, Bad Säckingen, Germany) was an important improvement to minimize potential errors in color matching. The Vita 3D Master shade guide, due to the equidistant distribution of the available colors in color space, has made the color match procedure straighter. In addition the different shade tabs are more uniformly spaced compared to other shade guides (Bayindir et al., 2007; Paravina et al., 2002). Hammad et al. (2003) reported that the Vita 3D Master shade guide is associated with significant intrarater repeatability improvement among general dentists when compared with the Vita Lumin Vacuum shade guide.

When comparing the ability of a ceramic system marketed both in Vitapan Classical and in Vita 3D Master shade guide to correctly match the selected shade, Corciolani et al. (2009) found that Vita Omega 900 in Vita 3D Master shade guide exhibited a closer color match than the same ceramic system in Vitapan Classical. Therefore, the higher color match could be considered to be shade guide dependant. Considering this result, the aim of this study was to test by means of a clinical spectrophotometer the ability of two different dental porcelain systems to correctly reproduce the selected shade color with reference to Vita 3D Master shade guide. Among ceramic materials, the 2 porcelains selected for this study are actually the only systems manufactured according to Vita 3D Master shade guide. The null hypothesis was that no difference existed between the two ceramic systems in the correct reproduction of the selected color.

Material and Methods

Two ceramic systems were selected for this study: (1) Vita Omega 900 Metallkeramik (Vita Zahnfabrik, Bad Säckingen, Germany) and (2) Vita VM13 (Vita Zahnfabrik, Bad Säckingen, Germany), both based on Vita 3D Master shade guide. The clinical spectrophotometer VITA Easyshade (Vita Zahnfabrik, Bad Säckingen, Germany) was used to measure color differences. The repeatability of color readings and therefore the use of this clinical spectrophotometer for research purposes was previously tested (Corciolani et al., 2006). To verify the color reliability of the 2 ceramic systems object of the study, 15 ceramic discs were fabricated with different layer thicknesses for each ceramic system, for a total of 30 specimens. The overall thickness of the specimens remained constant throughout at 1.3 mm thickness of ceramic fired over 0.3 mm thickness of a base metal alloy (Biomate-C; Silpo, Rome, Italy) framework. This total thickness was selected on the basis that the recommended degree of tooth reduction for metal ceramic restorations is 1.6 mm at the middle third of the tooth (Shillingburg et al., 1991).

Auto-polymerizing acrylic resin discs (DuraLay, LOT 052802; Reliance Dental Manufacturing Co, Worth, Ill), 0.3 mm in thickness and 15 mm in diameter were made in a cylindrical stainless steel mold. After placing the material into the mold, a glass plate was pressed onto the superficial layer to obtain a flat surface. Care was taken to avoid bubble formation within the acrylic resin. After polymerization, the acrylic resin specimen 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) and filled with a base metal alloy (Biomate-C; Silpo). The resulting disc-shaped specimens were roughened with an airbone-particle abrader (Skylab; Tecnogaz, Parma, Italy) using AlO_2 particles of 100 µm diameter (Aluminium Oxide, Ronvig Dental Mfg, Daugaard, Denmark) at 6 bars pressure. Flat disc specimens were used in the study to facilitate the process of obtaining controlled thicknesses of the ceramic layers, since Barrett et al. (2002) found no significant differences in shade matching accuracy between tab and disk design.

The selected color was 2M3 in the Vita 3D Master shade guide. Following the manufacturer's instructions, a wash opaque layer was applied first and fired in a ceramic furnace (Vacumat 500; Vita Zahnfabrik), followed by a second opaque layer which was added and fired.

At this stage the first opaque dentin layer was applied in a thickness controlled by the regulated 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 furnace. All the veneering materials were produced by the same manufacturer (Vita Zahnfabrik) (Table I).

Table I. Materials used for veneering procedures

	Omega 900	**Batch**	**VM 13**	**Batch**
Wash Opaque	2M3 Opaque 9037	6203J	WO Wash Opaque Paste 359	7666
Opaque	2M3 Opaque 9037	6203J	OP2 Opaque Paste 352	7739
Opaque Dentin	2M3 Opaque Dentine 9033	11690	2M3 Base Dentine 040	7516
Dentin	2M3 Dentine 9053	7999	2M3 Dentine 070	7468
Enamel	EN2 Enamel 9072	15200	ENL Enamel 191	7933

Finally, for each specimen a glaze firing was made according to the manufacturer's instructions. The firing cycles were performed strictly following manufacturer's instructions. At the end of each firing cycles, each layer was measured by an electronic digital caliper (1651 DGT; Beta, Milan, Italy) with a 10 µm accuracy. The thickness of each layer was considered acceptable for the study only when the variation in thickness was ± 20 µm. The thicknesses of the specimens are shown in Table II.

Table II. Layering schemes of the ceramic specimens

Sample		LP	Alloy	Opaque	Opaque Dentine	Dentine	Enamel	Final
O900	**VM 13**							
1-5	16-20	1	0.30mm	0.15mm	0.25mm	0.60mm	0.30mm	1.30mm
6-10	21-25	2	0.30mm	0.15mm	0.35mm	0.70mm	0.10mm	1.30mm
11-15	26-30	3	0.30mm	0.15mm	0.45mm	0.50mm	0.20mm	1.30mm

*LS = Layering Scheme

These layering schemes were selected on the basis of recommendations from the manufacturer. Since Fazi et al. (2009)

found that a proper color match cannot be guaranteed by solely relying on layering schemes (LS) recommended from manufacturers, 2 further slightly different layering schemes, already tested in a previous study (Corciolani et al., 2009), were evaluated.

The measurements were made with the clinical spectrophotometer Vita Easyshade. The color evaluation was performed by placing hand piece of the instrument on a stand, thus standardizing position and distance to minimize the reading error (Corciolani et al., 2006). “Restoration” mode was selected on the spectrophotometer and used throughout. In “Restoration” mode, the instrument compares the color parameters of the examined restorations with the preset color parameters of the selected shade. The values are expressed as differences between the data stored in the instrument and the measured specimens, and expressed in Chroma (the aspect of color in the Munsell color system by which a sample appears to differ from a gray of the same lightness or brightness and that corresponds to saturation of the perceived color) (Hunter et al., 1987), Hue (the attribute of color perception by means of which an object is judged to be red, yellow, green, and so forth) (Hunter et al., 1987) and Lightness (the perception by which white objects are distinguished from gray objects and light from dark colored objects) (Hunter et al., 1987).

Even if the Chroma, Hue and Lightness are singularly important in order to better understand the differences between the data stored and the data from the specimens, for calculating the color differences the ΔE (distance between points representing colors in the color space having rectangular coordinates) (Hunter et al., 1987) is the most important parameter, according with the formula proposed by Clarke (1983). For this reason, in the present study ΔE values were statistically analyzed.

To determine the significance of the differences in shade match recorded by the 2 groups, having checked that ΔE data distribution was normal according to the Kolmogorov-Smirnov test (P=.642) and that group variances were homogeneous using the Levene test (P=.204), the two-way Analysis of Variance (ANOVA) was applied with ΔE as the dependent variable, ceramic system and layering scheme as factors. The Tukey HSD (Honestly Significantly Different) test was applied for multiple comparisons. In all the tests the level of significance was set at α=.05.

Results

Tables III and IV report the color values measured with the Vita Easyshade spectrophotometer for Vita Omega 900 and Vita VM13 respectively. The outcome of the two-way ANOVA is reported in Table V. The two-way ANOVA revealed that the ceramic system significantly influenced the ΔE values (P<.001).

Table III. Vita Easyshade color evaluation for Omega 900 in Vita 3D Master shade guide (2M3) ceramic system. In the first column the scanning data for each sample are indicated. In the other columns there are the means (± SD) of the values of ΔE and of Delta related to Lightness, Chroma and Hue, because the Easyshade spectrophotometer makes comparison measurements.

Sample	ΔE	ΔC	ΔH	ΔL
1-5	2.30 ± 0.16	-1.94 ± 0.19	-3.18 ± 0.15	-0.18 ± 0.41
6-10	1.76 ± 0.05	-0.64 ± 0.17	-4.20 ± 0.05	-0.40 ± 0.19
11-15	1.34 ± 0.05	-0.02 ± 0.29	-3.22 ± 0.04	0.50 ± 0.16

Specifically, regardless of the layering scheme, VM13 had significantly lower ΔE values than Omega 900. The layering scheme was a significant factor for ΔE values (*P*<.001).

Table IV. Vita Easyshade color evaluation of VM13 ceramic system in 2M3 shade. In the first column the scanning data for each sample are indicated. In the other columns there are the means (± SD) of the values of ΔE and of Delta related to Lightness, Chroma and Hue, because the Easyshade spectrophotometer makes comparison measurements.

Sample	ΔE	ΔC	ΔH	ΔL
16-20	1.98 ± 0.08	-1.96 ± 0.09	0.36 ± 0.18	0 ± 0.12
21-25	1.64 ± 0.11	0.96 ± 0.09	-2.06 ± 0.09	1.04 ± 0.27
26-30	1.20 ± 0.10	-0.56 ± 0.11	-2.40 ± 0.05	0.50 ± 0.10

Table V. Two-way ANOVA for shade match.

	df	Sum of Squares	Mean Square	F	P
Ceramic	1	.280	.280	27.574	.000
LS	2	3.785	1.892	186.131	.000
Ceramic*LS	2	.061	.30	2.984	.042

When means were compared, the Tukey test for pairwise comparisons revealed that the ΔE values were lower for the LS3[a] than for the LS2[b], whose ΔE values were in turn lower than those of LS1[c] (significant differences reported in Table VI - LS column). Also the ceramic system-layering scheme interaction was found to be statistically significant, and the Tukey test consequently applied for pairwise comparisons revealed that when layered according to LS1, Vita VM13[C] resulted in a closer shade match when compared with Vita Omega 900[D] (significant differences are reported in Table VI - Significance column).

Table VI. Descriptive statistics of ΔE values recorded in the experimental groups. In the LS column, different superscript letters label significant differences when the layering scheme means were compared with the Tukey test (*P*<.05). In the significance column, different capital letters label significant differences when the ceramic system*layering scheme means were compared with the Tukey test.

LS	Ceramic	Mean	SD	Significance
1[c]	Omega 900	2.3	0.16	D
	VM13	1.98	0.08	C
2[b]	Omega 900	1.76	0.05	B
	VM13	1.64	0.11	B
3[a]	Omega 900	1.34	0.05	A
	VM13	1.2	0.1	A

Discussion

The null hypothesis that no difference existed between the 2 ceramic systems to correctly match the selected color was rejected, because Vita VM13 resulted in a closer color match (*P*<.001).

Despite the plethora of available information concerning dental ceramic manufacturing, the importance of layering in order to achieve the best color match is often not addressed with a sufficient scientific rationale. The problem is most often managed subjectively using the skill and experience of the individual ceramist involved. To have a more objective and scientific approach to the problem, the baseline reference for the current investigation was the information about layering taken from the diagrams supplied in the manufacturer's instructions (Fazi et al., 2009).

Of the 3 layering schemes chosen, the LS2 was prepared following the manufacturer's information obtained from the diagrams. The other 2 layering schemes followed were slightly different to evaluate the possible influence that variations in layering could have in color match, as ceramists work free-hand and this could result in small differences in the layers of the artifacts. The various schemes followed differed from each other in the ratios used of the base/opaque dentin and the dentin layer relative to the thickness of the enamel layer.

The 2 ceramic systems tested are both based on the Vita 3D Master shade guide. In a previous study, when comparing the same ceramic system (Vita Omega 900) using the Vitapan Classical and Vita 3D Master shade guide, specimens of Vita Omega 900 layered in 3D

Master reported a closer shade match when compared to specimens of the same ceramic system layered in Vitapan Classical (Hammad, 2003).

Concerning with acceptability and perceptibility tolerance of shade mismatch in a clinical setting, Douglas et al. (2007) found that the predicted color difference at which 50% of the dentist could perceive a color difference (50/50 perceptibility) was 2.6 ΔE units, and the predicted color difference at which 50% of they would remake the restoration due to color mismatch (clinically unacceptable color match) was 5.5 ΔE.

In the present study, an analysis of the values obtained from the Easyshade spectrophotometer (table III and IV), shows that all the specimens have values of ΔE below 2.6 ($1.10<\Delta E<2.46$). When means were compared, the factor layering scheme resulted in significant interaction ($P<.05$). Analyzing the values in Table VI, it can be highlighted that the closest shade match was achieved for the LS3, where the ratio between base/opaque dentin and dentin was 1:1 and the thickness of the enamel layer was 0.20 mm. Considering LS2, where two parts dentin were layered upon one part of base/opaque dentin (ratio 1:2) and the thickness of the enamel was 0.10 mm, no differences were found between Omega 900 and VM13 in shade match. For what about concerning LS1, which had the same layering ratio between base/opaque dentin and dentin as LS2 but a thicker enamel layer (0.30 mm versus 0.10 mm), an enhanced shade match was found for specimens manufactured with VM13[C] (Mean of ΔE=1.98

± 0.08) rather than the Omega 900[D] (Mean of ΔE=2.30 ± 0.16). It could be speculated that this trend may be due to the difference in hue (H) between the two ceramics, as the differences in Chroma (Omega 900 ΔC= -1.94 ± 0.19; VM13 ΔC= -1.96 ± 0.09) and Lightness (Omega 900 ΔL= -0.18 ± 0.41; VM13 ΔC= 0 ± 0.12) showed to be very similar for the 2 ceramic tested, thus scarcely influencing the ΔE. Conversely, an analysis of the value ΔH (difference in Hue) in table 3 and 4 for the LS1 (specimens #1-5 Table III and #16-20 Table IV) revealed that VM13 (ΔH= 0.36 ± 0.18) obtained better results than Omega 900 (ΔH=-3.18 ± 0.15). In the present study, only one color of the 2 ceramic systems has been analyzed. Therefore, considering this limitation, the results has necessarily to be considered as a trend in assessing if the ceramic systems are able to correct match the aimed shade. Even taking into account this limitation, the importance of the knowledge of the behavior of each ceramic system appear to be decisive in order to obtain a proper color match between the intended shade and the ceramic artifact.

As different ratio between layers ended in significant differences, it may be of scientific and clinical interest to further investigate the relative contribution of each layer to the final color for each single ceramic system.

Conclusions

Within the limitations of this study, it can be stated that both Vita VM13 and Vita Omega 900 ceramics exhibited an acceptable ability to correctly reproduce the selected shade color with reference to the Vita 3D Master shade guide. The layering scheme influenced the final color of the restoration. For the investigated ceramic systems and for the color tested, the closest shade match was achieved when a ratio of 1:1 between base/opaque dentin and dentin was used, in combinations with an overlaying 0.20 mm thick enamel layer.

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CHAPTER 5

5.1 Influence of layering thickness on the color parameters of a ceramic system.

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Introduction

The achievement of natural looking restorations has always been one of the greatest challenges in restorative and prosthetic dentistry. The correct integration with the biological tissues combined with an appropriate morphological function, are the goals that clinicians and technicians aspire to in everyday dental practice.

Dental porcelain, combining wear resistance, strength, toughness and aesthetics is the material most suitable for replacing natural tissue. Dental porcelain does have limitations in that it is not easy to use and aesthetic excellence is not always easy to obtain (Wee et al., 2002; Bergman et al., 1999; Sjögren et al., 1999). 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.

Shade selection has been the subject of several investigations (Wee et al., 2002; Hammad et al., 2003; Baltzer et al., 2005; Douglas, 1997), and since it cannot be considered a purely scientific procedure, it is often considered 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 is a problem. Douglas et al. (2003) found that the ability to reproduce the color of the target shade tab differed among laboratories and most crowns fabricated by the laboratories in their study, when compared to the prescribed shade tab, were above the clinical threshold for an acceptable shade match (ΔE=3.7). 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 (Ozturk et al., 2008), glazing (Yilmaz et al., 2008), the mixing ratio between powder and liquid (Zhang et al., 2004), different substructures (Kourtis et al., 2004) and layering (Dozic et al., 2003; Jarad et al., 2007).

Dozic et al. (2003) 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.

Jarad et al. (2007) 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).

Corciolani et al. (2009) 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.

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

The formulated null hypothesis was that the thickness of each layer did not significantly influence the final color of the porcelain fused to metal restorations.

Materials and Methods

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

The stand-alone clinical spectrophotometer VITA Easyshade (Vita Zahnfabrik) was used to measure color differences. The repeatability of color readings and therefore the possibility to use this clinical spectrophotometer for research purposes was previously tested (Corciolani et al., 2006).

In order to verify the influence of the thickness of each layer on the color parameters, 40 ceramic discs were fabricated with different layer thicknesses.

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 mould. After placing the material into the mould, a glass plate was pressed onto the most superficial layer in order to obtain a flat surface. A great deal of care was given to avoiding bubble formation within the resin.

After curing, the resin sample was extracted from the mould, put in a refractory cast filled with investment (GC Stellavest, GC Europe, Leuven, Belgium), and placed in a burnout furnace (Ovomat 7, Manfredi-SAED, Torino, 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, Italy).

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

Procedure for manufacturing specimens.

Flat disc specimens were used in the study in order to facilitate the process of obtaining controlled thicknesses of the ceramic layers, since Barrett et al. found no statistically significant differences in shade-matching accuracy between tab and disk design (Barrett et al., 2002).

The selected color was 2M3 in Vitapan 3D Master tooth guide. Following the manufacturer's instructions, 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 dentine layer was applied in a thickness controlled by the mould and fired following the manufacturer's firing instructions. A second dentine 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 1.

Table 1. Materials used for veneering procedures.

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

Finally, for each sample, a glaze firing was done according to the ceramic manufacturer's instructions.

A great deal of care was given to obtaining a controlled thickness of the veneering materials. Layering the ceramic into a calibrated mold with a 0.1 mm resolution allowed for a predictable thickness of each layer to be achieved, which was measured by an electronic digital caliper (1651 DGT, Beta, Milan, Italy) with a 10 µm resolution, after the firing process. The thickness of each layer was considered acceptable for the study only when the variation in thickness was ± 20 µm. The thicknesses of the specimens are shown in Table 2. All these layering patterns followed the "Vita VM13 Build Up

Layering” and they were selected on the basis of recommendations from the manufacturer (Vita Zahnfabrik, 2007).

Table 2. Layering patterns of the ceramic specimens

Sample	LP*	Alloy	Opaque	Base Dentine	Transpa Dentine	Enamel	Final	Ratio
1-5	1	0,30 mm	0,15 mm	0,35 mm	0,35 mm	0,15 mm	1,30 mm	1:1
6-10	2	0,30 mm	0,15 mm	0,25 mm	0,45 mm	0,15 mm	1,30 mm	1:2
11-15	3	0,30 mm	0,15 mm	0,30 mm	0,65 mm	0,20 mm	1,60 mm	1:2
16-20	4	0,30 mm	0,15 mm	0,45 mm	0,50 mm	0,20 mm	1,60 mm	1:1
21-25	5	0,30 mm	0,15 mm	0,40 mm	0,75 mm	0,30 mm	1,90 mm	1:2
26-30	6	0,30 mm	0,15 mm	0,75 mm	0,40 mm	0,30 mm	1,90 mm	2:1
31-35	7	0,30 mm	0,15 mm	0,70 mm	0,65 mm	0,50 mm	2,30 mm	1:1
36-40	8	0,30 mm	0,15 mm	0,90 mm	0,45 mm	0,50 mm	2,30 mm	2:1

Spectrophotometric Measurements

The spectrophotometer Vita Easyshade comprises a base unit and a hand piece. The color evaluation was carried out by placing the instrument on a stand, in order to minimize the reading error by standardizing position and distance (Corciolani et al., 2006). “Restoration” mode was selected on the spectrophotometer and used throughout.

Statistical Analysis

Delta C, Delta H, Delta L and Delta E values, were calculated by the spectrophotometer according to the formula proposed by Clarke (1983) and were subsequently 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 test was 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 $p<0.05$.

Results

Table 3 report the color values measured with the Vita Easyshade spectrophotometer for Vita VM13.

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, $p<0.05$).

Table 3. Vita Easyshade color evaluation of VM13 ceramic system.

Sample	ΔE	ΔC	ΔH	ΔL	Sample	ΔE	ΔC	ΔH	ΔL
1	1,0	-0,2	-1,0	0,9	21	2,1	-2,0	-2,2	0,0
2	1,1	-0,2	-0,9	1,0	22	2,3	-2,1	-2,2	-0,1
3	0,8	-0,5	-0,7	0,5	23	2,4	-2,2	-2,3	0,1
4	1,1	-0,5	-0,8	0,9	24	2,4	-2,3	-2,3	0,1
5	0,8	-0,2	-0,8	0,8	25	2,4	-2,3	-2,4	0,1
6	2,4	-1,3	0,0	2,0	26	1,0	0,0	-2,6	-0,4
7	2,0	-0,9	-0,1	1,8	27	1,1	-0,3	-2,7	-0,3
8	2,0	-1,1	0,1	1,6	28	1,1	-0,1	-2,6	-0,5
9	2,1	-1,2	0,3	1,8	29	1,1	-0,3	-2,5	-0,5
10	1,6	-0,8	-0,1	1,4	30	1,1	-0,3	-2,6	-0,5
11	0,7	-0,4	-0,6	-0,5	31	4,2	-3,9	-4,1	-0,3
12	0,6	-0,4	-0,7	-0,4	32	4,2	-3,9	-4,3	-0,5
13	0,8	-0,3	-0,7	-0,7	33	4,3	-4,0	-4,3	-0,4
14	0,8	-0,4	-0,7	-0,6	34	4,2	-3,9	-4,3	-0,4
15	0,7	-0,5	-0,6	-0,5	35	4,3	-4,1	-4,3	-0,2
16	1,6	0,2	-1,3	1,5	36	2,6	-2,4	-2,5	-0,5
17	1,9	0,2	-1,4	1,8	37	2,5	-2,3	-2,6	-0,5
18	1,6	0,1	-1,2	1,5	38	2,5	-2,3	-2,6	-0,6
19	1,6	0,2	-1,3	1,5	39	2,5	-2,3	-2,5	-0,6
20	1,8	0,3	-1,3	1,7	40	2,5	-2,3	-2,6	-0,5

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 (* LP) interactions were assessed at the univariate level.

		ΔC		ΔH		ΔL		ΔE	
LP	n	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

Discussion

The differences found in the color parameters and Δ 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 are different in their mathematic definition but may be correlated each other by the use of conversion formulas. For scientific purposes, the most commonly used system is the CIELab* system, in which L* value is the degree of the lightness of an object, a* value is the degree of redness or greenness, and b* value is the degree of yellowness or blueness (CIE, 1986).

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

Analysis of Hue (CIE, 1986), that is defined as the radial component of the cylindrical coordinates CIELab* and calculated according to the formula h_{ab} = arctan $\frac{b*}{a*}$ showed that by increasing the ceramic thickness, higher values of ΔH 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[c] (ΔH=-0,84±0,11), LP2[a] (ΔH=0,04±0,17) and LP3[b] (ΔH=-0,66±0,05), layered with different ratios between Base Dentine and Transpa Dentine (LP1=1:1, LP2 and LP3=1:2). Although it was not possible to find a direct correlation between a change in the ratio of the two dentin layers and a value in Hue, it could be speculated that, for the ceramic system object of this study, a closer correspondence in Hue can be obtained with smaller thicknesses.

Analysis of Saturation (or Chroma) (CIE, 1986), that is 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 Dentine resulted in a higher chromatic shade, that is a more intensive final color; whereas a greater amount of Transpa Dentine and Enamel reduced the Chroma. (Table 4)

The LP1[a] (mean ΔC=-0,32±0,16) and the LP2[b] (mean ΔC=-1,06±0,21) are two groups with the same final thickness but were layered following two different patterns with regards to the ratio between Base Dentine and Transpa Dentine (LP1=1:1 and LP2=1:2). A higher thickness of Base Dentine in LP1 resulted in a closer correspondence to the Chroma parameter. This trend is also confirmed after comparing LP5^{c} (mean ΔC=-2,18±0,13) with LP6^{a} (mean ΔC=-0,20±0,14), where for increased thickness the pattern with a higher ratio of Base Dentine (LP6=2:1) resulted in the closest Chroma correspondence.

The third parameter evaluated was the Lightness (or Value). It represents the lightness–darkness of a color (CIE, 1986). Value is the parameter most perceptible to human eyes, due to a greater number of rods (the photoreceptor cells involved in the transduction of monochromatic light into nerve signals that can be ultimately transmitted to the brain via the optic nerve) rather than cones (the photoreceptor cell that detects different colors) in the human retina. For this reason, an error in this parameter will have the greatest impact on the overall 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 Dentine porcelains in relation to the layer thickness of Base Dentine. Analyzing LP4^{d} (ΔL=1,60±0,14) and LP7^{b} (ΔL=-0,36±0,11) it can be shown, 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^{d} (ΔL=1,72±0,23) and LP5^{a} (ΔL=0,04±0,09), where the latter resulted in a lower value of ΔL and the thickness of the enamel layer was 0,30 mm.

For the ceramic system object of this test the ratio in thickness between Base Dentine and Transpa Dentine 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[a,b] (ΔE=0,96±0,15) in comparison with LP2[d] (ΔE=2,02±0,29), where the thickness of the veneering material was 1,0 mm, the ratio 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[a] (ΔE=0,72±0,08) when compared with 1:1 of the LP4[c] (ΔE=1,70±0,14). An increased thickness of veneering material, 1,60 mm and 2,00 mm adopted from LP5 to LP8 and the ratio 2:1 between Base Dentine and Transpa Dentine, resulted in a closer color correspondence. This trend was confirmed by LP6[b] (ΔE=1,08±0,04) when compared with LP5[e] (ΔE=2,32±0,13) and by LP8[e] (ΔE=2,52±0,04) when compared with LP7[f] (ΔE=4,24±0,05).

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. In order to achieve a certain shade, the technicians should basically respect the manufacturer instructions. As it is known that these instruction by themselves are not enough to be sure to obtain the aimed shade (Fazi et al., 2009), the findings of this paper may be useful in order to individually adjust the shade parameters. The human eye by itself can hardly evaluate selectively the three parameters. For this reason, the use of clinical spectrophotometers like Vita EasyShade that are capable to give Delta information of the three parameter individually, can greatly help.

Further study might be useful in order to investigate if the integration between the electronic information and the present layering data may result in a more accurate and easier shade match and/or give the technician the indication for adjusting a color that do not completely match the intended one for a ceramic restoration.

Conclusions

Within the limitations of this study, in 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 Dentine and Transpa Dentine had a great impact on the final color, as giving predominance to portion of Base Dentine resulted in a more Chromatic shade; conversely, the predominance of Transpa Dentine and Enamel reduced the Chroma of the color. An increase of the thickness of the Enamel layer resulted in a decrease in Lightness (Value) and vice-versa a decrease in the thickness of Enamel layer gave as result an increase in Lightness (Value).

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CHAPTER 6

6.1 Summary, conclusions and future directions

Summary

In **Chapter 1**, the rationale of this study has been presented. Accurate shade matching has always been one of the most challenging aspects of the restoration of of teeth and aesthetic dentistry generally. Due to the great variety of natural tooth color, achieving a close shade match of an artificial restoration with natural dentition still remains a complex process. Two major aspects of color matching procedures were presented. One is the selection of a color, through a shade guide, which will harmoniously integrate itself with the surrounding biological tissues and the other one is the correct reproduction of this color in the prosthesis or restoration.

After a brief summary of the scientific discoveries from Newton's experiments during the 18th century to the CIELab* color classification, some considerations were made about the use of ΔE to correlate color numerically and finally calculate the differences between two colors using a formula that gives one number as value for color differences. Although the importance of this finding changed the concept of color science, dental practice did not catch on immediately from this opportunity to improve the ability for color matching and visual assessment remained the benchmark procedure.

A critical review of the evolution of the most important shade guides was presented. Special attention was given to the scientific color distribution introduced by the VITA 3D Master Toothguide. It has a systematic arrangement of shades within the natural tooth color space and an objective numerical measure of color, according to the colorimetric CIELab* order principle, rather than on the mere observation of the natural tissue aspects belonging to the previous shade guides such as Vitapan Classical or Ivoclar-Vivadent Chromascop.

Further research pursued the objective of minimizing color mismatch due to visual estimation, by using colorimeters and spectrophotometers. A brief description of the differences between these instruments was provided. Particular attention has been focused on VITA Easyshade and its evolution (VITA Easyshade Compact) and on MHT Spectro Shade Micro, as these instruments are two of the most routinely used clinical spectrophotometers.

As previously introduced, the last step in color matching procedures is represented by the correct color reproduction in the prosthesis or restoration. A brief discussion about the factors that influence the final color of porcelain restorations was given, especially highlighting the predominant role played by the layering ratio between opaque and translucent shades. Even a correct shade selection is not enough if there is no correlation with thickness and layering of the restoration.

Therefore, the work described in this thesis aimed to provide an insight into the dental color matching procedure, as well as to elucidate how the achievement of a natural looking restoration could not dispense with a correct selection of the color followed by its accurate reproduction.

In **Chapter 2**, the measurement repeatability of a clinical spectrophotometer was compared with an established laboratory one. The initial step in the evaluation of the clinical use of the VITA Easyshade dental spectrophotometer was to consider its reliability. For this reason, the first phase was to evaluate the repeatability of readings taken by the instrument, as a mandatory requirement to further evaluate the performances in comparison with that of the Ocean Optics PSD 1000, as an established lab instrument.

Metal ceramic specimens layered according to different amounts of opaque and translucent porcelains were manufactured in order to perform repeated measurements. The Ocean Optics PSD1000 was tested measuring the color values of each specimen 5 times, while for VITA Easyshade the measurements were repeated 5 times by free hand and 5 times fixing the measuring probe to a stand, in order to test if there were any differences between clinical use (free hand) or lab use (fixed to a stand). The spectrophotometer repeatability was statistically evaluated by analyzing the Coefficient of Variation (CV).

The results demonstrated an excellent scanning repeatability for both the instruments tested. Very low values of coefficient of variation ($0,002<CV<0,111$) were obtained for the Ocean Optics

PSD1000. The Easyshade showed good accuracy in repeated scanning obtained both by fixing the handpiece of the device to a stand (0<CV<0,022) and by free hand (0,008<CV<0,913).

The good accuracy shown by the clinical instruments compared to the lab one, in performing repeated measurements revealed the possibility of using it both for clinical use and for in vitro testing.

In **Chapter 3**, the variations in color between four dental porcelain systems and the target shades “A2, A3 and A3.5” of the shade guide Vitapan Classical were investigated. An important source of variability of the color is represented by the porcelain thickness, by the need of having different layers of porcelain such as opaque, dentin and enamel. Considering the very limited information available from the manufacturers or from the literature, on what the ideal proportion of dentin and enamel should be, the object of this study was to verify if all the ceramic systems tested were able to correctly match the selected shade following the layering diagrams reported in the manufacturers’ instructions.

This study was performed by assessing the color match of the disc-shaped porcelain fused to metal restorations by using the VITA Easyshade clinical spectrophotometer. Three different shades (A2, A3, A3.5) for four different ceramic systems (VITA Omega 900, Duceram Kiss, Wieland Reflex and Ivoclar IPS d.SIGN) were investigated resulting in a total of 12 combinations. For each group, three samples were fabricated for a total of 36 specimens. Values of ΔE ranged between 1.2 and 5.0. Shade clinical matching ($\Delta E \leq 3.7$) was recorded for shade

A2 in all the ceramic systems, for shade A3 in Duceram Kiss and Ivoclar IPS specimens and for shade A3.5 only in VITA Omega 900 specimens. All the other specimens failed to achieve shade matching. ANOVA analysis showed no statistically significant differences ($P > 0.05$) between the porcelain brands. One-way ANOVA showed that the ceramic shade significantly influenced the ΔE values ($P < 0.05$).

In conclusion this study showed that the guidance given by the manufacturer to help the technician to obtain the color match between the selected shade and the final restoration, is very limited, and not sufficient to avoid color mismatch.

In **Chapter 4** two important factors affecting the shade match were investigated: the influence of the shade guide and the influence of the ceramic system. In **Paragraph 4.1** the ability of VITA Omega 900 ceramic system to correctly reproduce the selected shade color with reference to the Vitapan Classical and VITA 3D-Master Toothguide was tested. VITA Omega 900 was the object of this study because it was, at the time of the test, the only dental ceramic system marketed in Vitapan Classical shade guide as well as in VITA 3D-Master Toothguide. Today, even VITA VM13 is marketed both in Vitapan Classical and in VITA 3D-Master Toothguide.

Fifteen ceramic discs were fabricated with different layering patterns for each shade (A3 and 2M3), keeping constant the specimen total thickness. Three distinct layering patterns were realized that differed according to the thickness of the opaque dentin, dentin, and enamel layers, in order to create a variability in color reading. The color evaluation was done with the Easyshade and “Restoration” mode was selected using A3 and 2M3 shade as comparison. The Two-Way ANOVA test showed that both the interaction “shade guide-ceramic system” and the factor “layering pattern” significantly influenced the ΔE values (p<0,001). Specimens of VITA Omega 900 in the VITA 3D-Master Toothguide exhibited for the investigated shade a closer match in color than specimens of the same ceramic system in the Vitapan Classical shade guide. This result can be explained by the ability of Easyshade to better match colors that are organized in a scientifically-based systematic spatial distribution.

Therefore, the higher color correspondence can be considered to be shade guide dependant. Moreover, the best color match resulted to be influenced from the pattern selected for porcelain layering procedure.

After establishing that the VITA 3D-Master Toothguide resulted in a closer color match, in **Paragraph 4.2**, the next stage examined the ability of two dental porcelain materials (VITA Omega 900 and VITA VM13) to correctly reproduce the selected shade color with reference to the VITA 3D-Master Toothguide, in order to understand if the color match was shade guide dependant or ceramic system dependant. The test was performed following the same methods as the previous one. Fifteen ceramic discs were produced with different layer thicknesses for each ceramic system in 2M3 shade. The color accuracy expressed in ΔE was tested with the VITA Easyshade. Two-way ANOVA tests showed that the factor “ceramic system” was not statistically significant (p=0.17); whereas, the factor “layering pattern” significantly influenced the ΔE values ($p<0.001$). All the specimens had values of ΔE below 3.3; this is considered to be appreciable by skilled operators but clinically acceptable.

When the metal ceramic specimens have been manufactured with ceramic systems based on VITA 3D-Master Toothguide, no differences were found between VITA Omega 900 and VITA VM13 in their ability to correctly match the desired shade. This finding suggested that, for the ceramic systems object of this study , the ability of color match with a desired shade had to be considered shade guide-dependent. Once more this study confirmed that the scheme followed for layering the porcelain upon the metal had a predominant role in achieving the selected color for restoration.

Such a finding established the relative influence of each porcelain layer (Base Dentine, Transpa Dentine and Enamel) on the color parameters (Lightness, Chroma and Hue) of the restorations, that was developed in **Chapter 5**. Forty ceramic discs were fabricated with a proprietary steel mould and individually checked after firing with a digital caliper 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 Easyshade clinical spectrophotometer was used for color comparison with the reference color data of the selected shade stored into the device. One-way ANOVA showed that the factor "layering pattern" significantly influenced the ΔE, ΔC, ΔH and ΔL ($p<0.001$).

Greater thicknesses of Base Dentine resulted in a more Chromatic shade. Conversely, greater thicknesses of Transpa Dentine 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. A closer correspondence in Hue was obtained with smaller thicknesses.

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. The technician has to be able to individually adjust color parameters in order to achieve a certain shade.

Conclusions

Within the limitations of the previous studies, the following conclusions may be drawn from our evaluation of the factors influencing dental color matching procedure:

1) Achieving a correct color match between natural dentition and restoration or prosthesis is a complex process which consists of two specific procedures: color selection and color reproduction.
2) VITA Easyshade clinical spectrophotometer revealed good accuracy, comparable to a laboratory device, in performing repeated measurements. This means the device can be used clinically as a routine office instrument and for in vitro testing.
3) The indications given from ceramic manufacturers to help the technicians to obtain the color match between the selected shade and the final restoration are very limited, and not sufficient to avoid color mismatch.
4) VITA 3D-Master Toothguide resulted in a higher color match when considered with Vitapan Classical shade guide, thanks to its systematic distribution of tabs according to an increasing gradient of Lightness and Chroma.
5) The ability of color match with a desired shade has to be considered shade guide dependent. The approach adopted for layering the porcelain upon the metal have a predominant role in achieving the selected color for the restoration.

6) Concerning VITA VM13, a greater thicknesses of Base Dentine resulted in a more Chromatic shade. Conversely, greater thicknesses of Transpa Dentine 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. A closer correspondence in Hue was obtained with smaller thicknesses.
7) Depending on the final thickness of the metal ceramic restoration, the individual thickness of each layer and the ratio between the layers both play an important role in achieving the best color match. The technician has to be able to individually adjust color parameters in order to achieve a certain shade.

Future Directions

The possibility to relate to science something that has always been considered an art form represents one of the greatest challenges in modern dentistry. Achieving a natural looking restoration which correctly integrates itself with biological tissue has always been influenced by the skill of the clinician or technician.

Clinical spectrophotometers have the capability to become routinely used office devices. They can be used to help less experienced clinicians in color matching procedures in order to avoid or at least reduce color mismatch.

Ceramic manufacturers should provide specific schemes on how to layer their porcelain material relating to the final thickness of the restoration in order to obtain the desired shade. Ceramic manufacturers should also provide systems marketed according to the VITA 3D-Master Toothguide.

Future experiments should evaluate the accuracy of other marketed clinical spectrophotometers. The influence of the thickness and of the layering schemes should be evaluated for other ceramic systems.

Clinical studies are necessary to support laboratory data, in order to make evidence that instrumental color detection may be as efficient as a human but more reliable; always considering that art is something related to humans and not to machines.

6.3 Riassunto, conclusioni e direzioni future

Riassunto

Nel **Capitolo 1** è stato presentato il fondamento logico di questo studio. La corretta procedura di presa del colore ha sempre rappresentato una delle maggiori sfide in odontoiatria restaurativa ed estetica. A causa della grande varietà di colore dei denti naturali, il raggiungimento di un'affine corrispondenza di colore tra un restauro artificiale e la dentatura naturale rimane ancora una procedura complessa. Sono stati presentati i due più grandi aspetti del processo di riproduzione del colore dentale: uno è rappresentato da una corretta scelta, mediante l'ausilio di scala di riferimento, di un colore che si integrerà armoniosamente con i tessuti biologici circostanti e l'altro aspetto è rappresentato dalla corretta riproduzione del colore scelto nell'elemento protesico o nel restauro conservativo.

Dopo un breve excursus circa le scoperte scientifiche a partire dagli esperimenti di Newton durante il XVIII secolo fino ad arrivare alla odierna classificazione del colore CIELab*, sono state valutate diverse considerazioni circa la possibilità data dall'introduzione del ΔE di relazionare il colore ai numeri, e quindi finalmente calcolare la differenza tra due colori mediante una formula che fornisse un numero come espressione di una differenza tra due colori. Sebbene questa scoperta avesse cambiato il concetto del colore come scienza, la pratica odontoiatrica non percepì immediatamente l'opportunità offerta da questo nuovo sistema di migliorare la corrispondenza del colore, e continuò a considerare come punto di riferimento la tecnica di presa del colore mediante valutazione visiva.

E’ stata presentata una revisione critica dell’evoluzione delle più importanti scale colori. Si è prestato una attenzione speciale alla distribuzione scientifica del colore introdotta dalla scala VITA 3D Master Toothguide. Tale scala offre, oltre a una disposizione sistematica delle tonalità di colore all’interno dello spazio colorimetrico dei denti naturali, la possibilità di misurare il colore in maniera oggettiva e secondo un ordine numerico, piuttosto che basandosi sulla semplice osservazione dell’aspetto dei denti naturali che invece appartiene alle scale colori precedenti, quali la Vitapan Classical o la Ivoclar-Vivadent Chromascop.

Come passo successivo la ricerca ha perseguito l’obiettivo di minimizzare sempre più la discrepanza di colore dovuta alla valutazione visiva mediante l’introduzione dei colorimetri e degli spettrofotometri. Dopo aver brevemente descritto le differenze tra questi due tipi di strumenti di misura, si è prestata particolare attenzione sullo spettrofotometro clinico Vita Easyshade e la sua evoluzione (Vita Easyshade Compact) e sullo spettrofotometro clinico MHT Spectro Shade Micro, in quanto questi rappresentano due tra gli strumenti clinici di misura del colore più venduti.

Come introdotto in precedenza, l’ultimo passo nell’ottenimento del risultato estetico è rappresentato dalla corretta riproduzione del colore scelto nell’elemento protesico o nel restauro conservativo. Sono stati brevemente analizzati i fattori che influenzano il colore finale dei restauri ceramici, mettendo specialmente in evidenza il ruolo predominante ricoperto dai rapporti di stratificazione tra gli strati di porcellana opaca e quelli più traslucenti. Tale passaggio per rimarcare il fatto che una corretta scelta del colore non è sufficiente a garantire il raggiungimento del successo estetico, se non correlata a una corretta tecnica di stratificazione.

Il lavoro descritto in questa tesi si auspica di fornire un quadro completo della procedura di riproduzione del colore dentale, al fine di chiarire come il raggiungimento di un'estetica il più naturale possibile non possa fare a meno di una corretta scelta del colore seguita da un'altrettanto corretta riproduzione.

Nel **Capitolo 2** è stata comparata la ripetibilità di lettura di uno spettrofotometro clinico con uno utilizzato per ricerche in laboratorio. Il primo passo nella valutazione dell'uso clinico dello spettrofotometro Vita Easyshade è stato valutare la sua affidabilità. A questo scopo la verifica preliminare è stata la valutazione della ripetibilità di lettura, in quanto requisito indispensabile per una successiva comparazione con lo spettrofotometro Ocean Optics PSD 1000, uno strumento di laboratorio estremamente affidabile.

Le misurazioni sono state ripetute su dei campioni di ceramica da rivestimento stratificata su metallo, variando la quantità di porcellana opaca e traslucida in diversi schemi di stratificazione. Le rilevazioni colorimetriche sono state ripetute 5 volte con lo spettrofotometro Ocean Optics PSD1000, mentre con lo spettrofotometro clinico Vita Easyshade sono state fatte 5 misurazioni, tenendo la sonda dello strumento con la mano e 5 volte fissandola a uno stativo graduato, al fine di valutare se esisteva qualche possibile differenza tra l'uso clinico dello strumento (a mano libera) e quello di laboratorio (fissato allo stativo). La ripetibilità di lettura degli strumenti è stata statisticamente testata mediante l'analisi del Coefficiente di Variazione (CV).

I risultati hanno dimostrato un'eccellente ripetibilità di lettura per entrambi gli strumenti testati. Lo spettrofotometro PSD1000 ha fornito dei valori di coefficiente di variazione molto bassi (0,002<CV<0,111). Per ciò che riguarda lo spettrofotometro Easyshade, la fedele accuratezza di lettura è stata ottenuta sia fissando la sonda allo stativo (0<CV<0,022) che a mano libera (0,008<CV<0,913).

Questo primo lavoro ha confermato la validità dell'uso dello spettrofotometro Vita Easyshade, sia in ambiente clinico, sia come strumento di ricerca, poiché la buona accuratezza di lettura dimostrata in misurazioni ripetute è risultata valida quanto quella dello strumento di laboratorio.

Nel **Capitolo 3** è stata investigata l'abilità di quattro sistemi ceramici differenti nel riprodurre il colore di diverse tinte appartenenti alla scala colori Vitapan Classical (A2, A3 e A3.5). Lo spessore della ceramica da rivestimento rappresenta un'importante variabile nella riproducibilità del colore, poiché una stratificazione anatomica è fatta da vari strati, quali l'opaco, la dentina e lo smalto, che differiscono tra loro per croma e opacità. Considerando la scarsezza d'informazioni disponibili dai produttori e dalla letteratura su quale dovrebbe essere la giusta proporzione di stratificazione di smalto e dentina, l'oggetto di questo studio è stato quello di verificare se tutti i sistemi ceramici testati fossero in grado di riprodurre correttamente il colore desiderato, attenendosi esclusivamente agli schemi di stratificazione forniti dai produttori.

Questo studio è stato condotto verificando il colore dei campioni metal-ceramici a forma di disco, mediante l'ausilio dello spettrofotometro clinico Vita Easyshade. Tre differenti colori (A2, A3 e A3.5), per quattro differenti sistemi ceramici (Vita Omega 900, Duceram Kiss, Wieland Reflex e Ivoclar IPS d.SIGN), sono stati oggetto della seguente indagine, ottenendo un totale di 12 combinazioni. Sono stati prodotti 3 campioni per ogni gruppo, per un totale di 36 campioni. I valori di ΔE ottenuti variavano da 1,2 a 5,0. Tutti i sistemi ceramici hanno dimostrato un'accettabile corrispondenza clinica del colore per la tinta A2 ($\Delta E \leq 3{,}7$), mentre solamente i sistemi Duceram Kiss e Ivoclar IPS per la tinta A3 e il sistema Vita Omega 900 per la tinta A3.5 hanno dato dei valori clinicamente accettabili. Per tutti gli altri campioni sono stati ottenuti dei valori di ΔE non accettabili. Il test statistico ANOVA non ha rivelato differenze statisticamente significative tra le ceramiche testate ($p<0{,}05$). Al contrario il test One-way ANOVA ha rivelato che il colore della ceramica influenzava significativamente i valori di ΔE ($p<0{,}05$).

Considerando i risultati di questo studio, si può asserire che le indicazioni fornite dai produttori di ceramiche dentali, per aiutare gli odontotecnici al raggiungimento del successo estetico, e quindi alla corrispondenza tra il colore del manufatto e quello scelto dal clinico,sono molto limitate, e spesso non sufficienti ad evitare discrepanze di colore.

Nel **Capitolo 4** sono stati analizzati due rilevanti fattori che possono influenzare la corrispondenza di colore: l'influenza della scala colori e quella del sistema ceramico scelto. Nel **Paragrafo 4.1** è stata testata l'abilità del sistema ceramico Vita Omega 900, nel riprodurre correttamente il colore scelto, in riferimento alle scale colori Vitapan Classical e Vita 3D-Master Toothguide. La ceramica Vita Omega 900 è stata scelta per questo test perché, al momento del test, era l'unico sistema ceramico dentale commercializzato sia nelle tinte della Vitapan Classical che in quelle della Vita 3D-Master Toothguide. Al giorno d'oggi, anche la ceramica Vita VM13 è commercializzata in entrambe le scale colore.

Sono stati fabbricati 15 dischi ceramici secondo schemi di stratificazione differenti per ogni colore (A3 e 2M3), mantenendo costante lo spessore finale del campione. Sono stati analizzati 3 differenti schemi di stratificazione, nei quali variavano gli spessori della dentina opaca, della dentina e dello smalto,al fine di creare una variabilità nella lettura del colore. La valutazione colorimetrica è stata effettuata mediante lo spettrofotometro Easyshade selezionando la modalità "Restauro" con riferimento ai colori A3 e 2M3. Il test ANOVA a due vie ha dimostrato che i valori di ΔE venivano influenzati significativamente, sia dall'interazione "scala colori-sistema ceramico", che dal fattore "schema di stratificazione" ($p<0,001$). I campioni di ceramica Omega 900 stratificati secondo la scala colori Vita 3D Master Toothguide hanno mostrato, per il colore selezionato, una corrispondenza migliore di colore rispetto ai campioni della stessa ceramica stratificati seconso la scala colori Vitapan Classical. Questo risultato può essere interpretato considerando che lo spettrofotometro Easyshade riesce meglio ad interpretare e riconoscere i colori organizzati secondo una distribuzione sistematica nello spazio colorimetrico dei denti naturali.

Da questi risultati si può dedurre che la migliore corrispondenza del colore possa essere considerata dipendente dalla scala colori scelta. Inoltre anche lo schema di stratificazione si è dimostrato determinante nella corretta riproduzione del colore stesso. Come passo successivo, dopo aver stabilito che la scala colori Vita 3D Master Toothguide permette una riproduzione del colore più affidabile, nel **Paragrafo 4.2** si è passati ad esaminare l'abilità di due differenti porcellane ad uso dentale (Vita Omega 900 e Vita VM13) nel riprodurre correttamente il colore scelto in riferimento alla scala colori Vita 3D Master Toothguide, al fine di comprendere se la migliore corrispondenza di colore fosse dipendente ancora dalla scala colori oppure potesse essere influenzata anche dal sistema ceramico scelto. Il test è stato condotto seguendo la stessa configurazione di materiali e metodi utilizzata nel precedente studio. Sono stati prodotti 15 dischi ceramici nel colore 2M3 secondo diversi schemi di stratificazione per ogni sistema ceramico. Per misurare l'accuratezza del colore espressa come valore di ΔE è stato usato lo spettrofotometro Vita Easyshade. Il test statistico ANOVA a due vie ha rivelato che il fattore "sistema ceramico" non era statisticamente significativo ($p=0,17$), mentre il fattore "schema di stratificazione" influenzava significativamente i valori di ΔE ($p<0,001$). Tutti i campioni testati avevano valori di ΔE minori di 3,3; in letteratura tale differenza, nonostante sia apprezzabile da operatori esperti, viene considerata clinicamente accettabile.

Concludendo, non sono state trovate differenze significative nella corretta riproduzione del colore quando i campioni metal ceramici sono stati stratificati con due sistemi (Omega 900 e VM13) basati entrambi sulla scala colori Vita 3D Master Toothguide. Questo risultato ha confermato il fatto che, per i sistemi ceramici oggetto di questo studio, la possibilità di avere una buona corrispondenza tra il colore scelto e quello realizzato nel manufatto deve essere condiserata dipendente dalla scala colori utilizzata. Ancora una volta questo studio ha messo in rielievo il fatto che lo schema seguito durante la stratificazione della ceramica sul metallo assume un ruolo fondamentale nel corretto ottenimento del colore scelto. Ciò ha stabilito l'influenza relativa di ogni strato di porcellana (Base Dentine, Transpa Dentine e Enamel) sui parametri del colore dei restauri (Tinta, Valore e Croma), che è stato in seguito approfondito nel **Capitolo 5**. Nel seguente lavoro sono stati prodotti 40 dischi metal ceramici mediante l'utilizzo di uno stampo in acciaio appositamente progettato e singolarmente verificati con un calibro digitale dopo ogni cottura, al fine di controllare lo spessore di ogni strato. Sono stati valutati 4 differenti spessori finali di porcellana nel colore 2M3. Per ogni spessore sono stati testati 2 differenti schemi di stratificazione. La rilevazione del colore è stata effettuata con lo spettrofotometro clinico Vita Easyshade, il quale calcola le differenze di colore tra quello rilevato dal campione e i dati memorizzati nello strumento. Il test statistico ANOVA ad una via ha rilevato che il fattore "schema di stratificazione" influenzava significativamente i valori di ΔE, ΔC, ΔH e ΔL ($p<0{,}001$). Spessori maggiori dello strato Base Dentine hanno provocato un aumento di Croma nel restauro. Al contrario, spessori maggiori dello strato Transpa Dentine e Enamel hanno prodotto una diminuzione del Croma del colore. L'incremento dello spessore dello strato Enamel ha prodotto una diminuzione del Valore e vice versa. Per quanto riguarda la Tinta, i campioni con gli spessori più sottili hanno dimostrato una corrispondenza maggiore.

A seconda dello spessore finale della metal ceramica, lo spessore di ogni strato e il rapporto tra i vari strati con diversa opacità ricoprono un ruolo predominante nel raggiungimento della migliore corrispondenza di colore. L'odontotecnico dovrebbe essere in grado di correggere individualmente i parametri del colore, al fine di ottenere la tinta desiderata.

Conclusioni

La valutazione dell'analisi dei fattori che influenzano la procedura di riproduzione del colore, tenendo sempre in considrazione i limiti degli studi presentati, ci consente di trarre le seguenti conclusioni:

1. L'ottenimento di una corretta corrispondenza di colore tra la dentatura naturale e il restauro conservativo o protesico è un processo complesso che consiste di 2 procedure specifiche: la scelta del colore e la sua corretta riproduzione.
2. Lo spettrofotometro clinico Vita Easyshade ha dimostrato un'ottima precisione nell'effettuare misure ripetute, paragonabile a quella dello strumento di laboratorio. Ciò sta a significare che lo strumento può essere utilizzato sia come strumento clinico, che per effettuare misurazioni in vitro.
3. Le indicazioni fornite dai produttori di ceramiche dentali, per aiutare gli odontotecnici ad ottenere la giusta corrispondenza tra il colore scelto dal clinico e quello del manufatto, sono molto limitate, e non sono sufficienti al fine di evitare le discrepanze di colore.
4. La scala colori Vita 3D Master Toothguide ha consentito di ottenere migliori corrispondenze di colore rispetto alla scala Vitapan Classical; ciò è dovuto alla distribuzione sistematica dei toni di colore secondo un gradiente incrementale di Valore e Croma.

5. La capacità di ottenere correttamente un colore con una ceramica deve essere considerata dipendente dalla scala colori utilizzata. L'approccio scelto per stratificare la porcellana sul metallo ricopre un ruolo predominante nell'ottenimento del colore prescelto per il restauro.
6. Per quel che riguarda il sistema ceramico Vita VM13, un incremento dello spessore dello strato Base Dentine produce un incremento del Croma. Al contrario, il Croma del restauro viene diminuito mediate l'incremento degli strati Transpa Dentine e Enamel. Un incremento dello strato Enamel produce una diminuzione della Luminosità (Valore) e vice versa. A spessori più sottili la ceramica ha dimostrato una migliore corrispondenza della Tinta.
7. A seconda dello spessore finale della metal ceramica, lo spessore di ogni strato e il rapporto tra i vari strati con diversa opacità ricoprono un ruolo predominante nel raggiungimento della migliore corrispondenza di colore. L'odontotecnico dovrebbe essere in grado di correggere individualmente i parametri del colore al fine di ottenere la tinta desiderata.

Direzioni Future

La possibilità di relazionare alla scienza un qualcosa che è sempre stata considerata una forma artistica rappresenta una delle più grandi sfide dell'Odontoiatria moderna. L'ottenimento di un restauro con sembianze naturali, ovvero che si integri correttamente con i tessuti biologici circostanti, ha sempre rappresentato una procedura dipendente dalle abilità del clinico o dell'odontotecnico.

Gli spettrofotometri clinici possiedono al giorno d'oggi tutti i requisiti per diventare strumenti d'uso quotidiano. Essi sono in grado di aiutare i clinici meno esperti nella procedura di selezione del colore, al fine di evitare, o quanto meno ridurre, le discrepanze che si possono verificare.

Al fine di ottenere il colore desiderato, i produttori di ceramiche dovrebbero fornire degli schemi dettagliati su come stratificare la loro porcellana in relazione allo spessore finale del restauro. Sarebbe utile che le ceramiche dentali fossero disponibili sul mercato anche in colorazione Vita 3D Master Toothguide.

Ulteriori esperimenti dovrebbero valutare la precisione degli altri spettrofotometri clinici presenti in commercio. Ulteriormente importante sarebbe valutare l'influenza che gli spessori e i vari schemi di stratificazione potrebbero avere sugli altri sistemi ceramici in commercio.

Al fine di validare questi dati di laboratorio sarebbero necessari studi clinici, con il fine di dimostrare che la rilevazione strumentale del colore può essere tanto efficiente quanto quella umana, ma più affidabile; sempre considerando che alla fine l’arte rimane sempre una virtù che appartiene agli esseri umani e non alle macchine.

6.3 Resumen, conclusiones y direcciones futuras

Resumen

En el **Capítulo 1**, se presentó el objetivo del estudio. La selección de un color preciso siempre ha sido uno de los aspectos más controvertido de la odontología estética en general cuando se desea restaurar un diente. Debido a la variedad de colores que caracteriza un elemento dental, lograr el color de una restauración artificial que pueda representar lo más fielmente posible lo de un diente naturale es un procedimento complejo. Se presentaron, entonces, los dos mayores aspectos de la toma del color. La primera se basa en la selección de un color, a través de una guía de colores, que se integre harmónicamente con los tejidos biológicos circumstantes, y el segundo es la correcta reproducción del color de la prótesis o de la restauración.

Tras un breve resumen del conocimiento científico, a partir de los descubrimientos de Newton en el siglo 18 a la clasificación del color de CIELab*, se presentaron algunas consideraciones acerca del utilizo de ΔE para la correlación numérica de los colores, para así poder medir las diferencias existentes entre dos colores utilizando una formula que permita representar los valores en numeros. A pesar de que este tema pueda cambiar el concepto de la ciencia del color, en la practica no se aprovechó de la oportunidad de este nuevo metodo para mejorar la correspondencia del color, pero sigue a ser tomada en consideración la técnica visiva de la toma del color.

Se presentó una revisión critica de la evolución de las guías de colores más importantes. Una consideración particular se hizo en la distribución científica del color introducida por VITA 3D Master Toothguide. Esta guía presenta una disposición sistematica de los colores entre aquellos presentes en un diente y una medida numerica objetiva del color, según los principios de la colorimetría CIELab, más bien que en la pura observación de los aspectos de un diente natural así como reportado en guías precedentes como por ejemplo en la de Vitapan Classical o en la de Ivoclar-Vivadent Chromascop.

Investigaciones adjuntivas se prefijaron el objetivo de disminuir los errores en la toma del color debido a la sola evaluación visiva, utilizando por ello colorimetros y espectofotometros. Se describieron brevemente las diferencias entre los dos instrumentales presentados. La atención se focalizó en VITA Easyshade y en su evolución (VITA Easyshade Compact) y en MHT Spectro Shade Micro, de momento que estos son los metodos espectofotometricos más utilizados en la practica clínica.

Según cuanto precedentemente introducido, la ultima etapa en la selección del color es su perfecta reproducción en la prótesis o en la restauración. Se discutó de los factores que pueden influenciar el color final de una restauración en ceramica, hacendo encapié en el papel fundamental jugado por la posibilidad de estratificar el opaco y el translúcido. Si no hay una correlación entre el espesor y el estratificación de la restauración, no es suficiente elegir corectamente el color. Por ello, el enfoque describido en esta thesis doctoral se propuso de ofrecer una visión completa de los procedimientos de la reproducción del color dental, para aclarar como, la realización de una estética dental lo más natural posible, necesita de una selección adecuada del color así como de su corecta reproducción.

En el **Capitulo 2**, se comparó la repetición de lectura de uno espectofotometro clínico con la de un aparato utilizado en laboratorio. La primera etapa en la evaluación del utilizo clínico del espectofotometro VITA Easyshade fue de analizar su fiabilidad. De hecho, antes te todo se evaluó la repetibilidad de las lecturas logradas por el aparato, que es un requisito indispensabile para poderlo luego comparar al espectofotometro de laboratorio Ocean Optics PSD 1000.

Se estratificaron diferentes cantitades de opaco y translúcido para la fabricación de especimenes de metalo ceramica según sugerido de los productores. Las medidas se repitieron 5 veces con el espectofotometro Ocenan Optics PSD 1000, y se conducieron 5 medidas con el espectofotometro clínico VITA Easyshade, mantenendo la sonda con la mano y otras 5 veces fijando la sonda a un andamio graduado, con el objetivo de evaluar posible diferencias entre el utilizo clínico del instrumental (con la sola mano) y aquello de laboratorio (fijado al andamio). La repetibilidad de lectura fue calculada estadisticamente a través del ánalisis del coeficiente de variación (CV). Los resultados demonstraron una repetibilidad optimal de lectura por ambos los aparatos testados. El espectofotometro PSD 1000 logró valores de coeficiente de variación bajos ($0.002<CV<0.111$). Con respecto al espectofotometro Easyshade, una repetición de lectura exacta se logró sea fijando la sonda al andamio (0<CV<0.022) sea utilizandola a mano libre (0.008<CV<0.913).

El primer estudio validó el utilizo del espectofotometro Easyshade sea clínicamente que como aparato de investigación, de momento que la precisión de lectura demonstrada en medidas repetidas fue comparable a aquella del mismo instrumental de laboratorio.

En el **Capitulo 3**, se investigó la capacidad de cuatro diferentes sistemas ceramicos en la reproducción del color de tintas diferentes perteneciente a la escala de colores Vitapan Classical (A2, A3 y A3.5). El espesor de la ceramica de revestimiento es otra variable importante durante la reproducción del color, de momento que una estratificación anatómica es compuesta de diferentes capas, por ejemplo el opaco, la dentina y el esmalte, los cuales se diferencian entre ellos por el croma y la opacidad. Tomando en consideración las pocas informaciones procurada por los productores y en la literatura sobre la que debería ser la exacta proporción de estratificación de esmalte y dentina, el objeto de estudio fue de averiguar si todos los sistemas de ceramicas disponibiles tenían la capacidad de reproducir correctamente el color deseado, siguiendo fielmente las líneas guías propuestas por los fabricantes.

La investigación se realizó averiguando el color de muestras de metalo-ceramica con forma de discos, utilizando el espetofotometro clínico VITA Easyshade. Por ello, se utilizaron tre colores (A2, A3 y A3.5) y cuatro diferentes sistemas de ceramica (VITA Omega 900, Duceram Kiss, Wieland Reflex e Ivoclar IPS d.SIGN) y se lograron hasta 12 combinaciones. Se producieron tres muestras cada grupo, por un total de 36 especimenes. Los valores obtenidos de ΔE se extendevano desde 1.2 hasta 5.0. Todos los sistemas ceramicos utilizados enseňaron una aceptable correspondencia clínica del color en la tinta A2 ($\Delta E \leq 3,7$), mientras que los sistemas Duceram Kiss e Ivoclar IPS y el sistema VITA Omega 900 revelaron valores clínicamente aceptables sólo por las tintas A3 y A3.5 respectivamente. Los demás especimenes alcanzaron valores de ΔE no aceptables. El ánalisis estadístico (ANOVA) no reveló diferencias significativas entre las ceramicas testadas ($p<0.05$). El ánalisis a una variancia de ANOVA desveló que el color de la ceramica era una factor significativamente influyente los valores de ΔE ($p<0.05$).

Analizando los resultados obtenidos del precedente estudio, se puede afirmar que las indicaciones ofrecida por los fabricantes de las ceramicas dentales, para ayudar los técnicos en alcanzar el éxito estético y en la correspondencia entre el color del manufacto y aquello elegido por el dentista, son limitadas y muy a menudo no son suficientes para evitar discrepancias en el color.

En el **Capitulo 4**, se analizaron los factores que pueden influenciar la correspondencia del color: la escala de colores de un lado y el sistema ceramica elegido de otro. En el **Parrafo 4.1**, se testó la habilidad de VITA Omega 900 en reproducir el color seleccionado tomando en consideración las escalas de colores Vitapan Classical y Vita 3D-Master Toothguide. La elección del sistema ceramica VITA

Omega 900 fue guíada porque, al momento del estudio, era la sóla ceramica disponibile sea en las tintas Vitapan Classical que en aquellas de Vita 3D-Master Toothguide. Hoy en día, también la ceramica Vita VM13 está disponibile en el comercio.

Se prepararon 15 discos de ceramica siguiendo planes de estratificación diferentes por cada color (A2 y 2M3), mantenendo costante el espesor final de la muestra. Se analizaron 3 esquemas de estratificación, variando las capas de la dentina opaca, de la dentina y del esmalte para crear una variabilidad en la lectura del color. Las medidas del color se cumpliron utilizando el espetofotometro VITA Easyshade seleccionando la modalidad "Restauración" y referiendose a los colores A2 y 2M3. El test ANOVA de dos vias reveló que los valores de ΔE se veían influenciados significativamente por la interacción "escala de color-sistema de ceramica" y del factor "esquema de estratificación" ($p<0.001$). Las muestras de Omega 900 estratificados siguiendo la escala de colores Vita 3D Master Toothguide demonstraron, por el color seleccionado, una mejor correspondencia del color con respecto a las muestras de la misma ceramica cuya estratificación fue guíada por la escala de color Vitapan Classical. La interpretación de estos resultados tiene en consideración que el espectofotometro Easyshade puede interpretar de manera más valida y reconocer los colores según una distribución sistematica en el espacio colorimetrico de los dientes naturales.

Consecuentemente, una exacta correspondencia del color no puede prescindir de la escala de colores elegida. Además, el plan de estratificación del color demonstró ser otro factor determinante la correcta reproducción del color.

Sucesivamente, tras establecer que la escala de color Vita 3D Master Toothguide permite lograr una reproducción del color más fiable, en el **Parrafo 4.2** se examinó la habilidad de dos ceramicas dentales (Vita Omega 900 y Vita VM13) en la exacta reproducción del color elegido referiendose a la escala de colores Vita 3D Master Toothguide, para así comprender si la mejor correspondecia del color dipendiera todavía de la escala de colores o si pudiera ser influenciada del mismo sistema de ceramica utilizado. El test se condujo utilizando el mismo protocolo del estudio precedente. Se construyeron 15 discos de ceramica en el color 2M3 siguiendo esquema de estratificaciones diferentes por cada ceramica. La precisión del color (ΔE) se midió a travès del espetofotometro Vita Easyshade. El ánalisis estadístico reveló que el factor "sistema de ceramica" no fue significativo ($p=0.17$), mientras que el factor "esquema de estratificación" influyó significativamente ($p<0.001$). Todos los especimenes testados lograron valores de ΔE menor de 3.3; en la literatura dicha diferencia, a pesar de que sea apreciata por operatores esperto, es clínicamente aceptable.

En conclusion, no se encontraron diferencias significativas en la reproducción correctas del color cuando las muestras en metalo-ceramica se estratificaron con dos sistemas (Omega 900 y VM13) siguiendo la escala de colores Vita 3D Master Toothguide. Esto en confirmación de que, por los sistemas testados en el presente estudio, la buena correspondencia del color elegido y de aquello realizado en el manufacto protesico es dependiente de la escala de colores utilizada. Además, el esquema de estratificación de la ceramica sobre el metal tiene un papel importante en la correcta obtención del color elegido. La influencia relativa de cada capa de ceramica (Base Dentine, Transpa Dentine y Enamel) en los parametros de los colores de las restauraciones (Tinta, Valor y Croma) se aprofundió en el **Capitulo 5**. Por ello, se realizaron 40 discos de metal-ceramica utilizando un molde en acero apositamente creado y cada disco fue singolarmente medido con una calibro digital tras las varias cocciones para averiguar el espesor de las muestras. Se evaluaron 4 diferentes grosores finales de ceramica en el color 2M3. Por cada espesor, se testaron 2 esquemas de estratificación. Las medidas se realizaron utilizando el espetofotometro clínico Easyshade, que permite calcular las diferencias de color entre aquello registrado por el especimen y aquello memorizado en el aparato. El ánalisis estadístico reveló que el factor "esquema de estratificación" influyó negativamente en los valores de ΔE, ΔC, ΔH y ΔL ($p<0.001$). Al aumentar de la capa de Base Dentine se asistió a un aumento en el croma de la restauración. Contrariamente, espesores mayores de Traspa Dentine y Enamel disminuiron el croma del color. El aumento de la capa de Enamel provocó un decaimiento del valor y *vice versa*. Con respecto ala Tinta, las muestras con menores espesor demonstraron una correspondencia mayor.

Según el espesor final de una metalo-ceramica, el grosor de cada capa y la relación entre los varios estratos con diferente opacidad tienen un papel fundamental en la obtención de la mejor correspondencia del color. El técnico dental debería ser capaz de corregir individualmente los parametros del color, para así lograr la tinta deseada.

Conclusiones

La evaluación del ánalisis de los factores que influencian los procedimientos de reproducción del color, entre los limites de las investigaciones presentadas, nos permite definir las conclusiones siguientes:

1) La obtención de una correcta correspondencia de color entre el diente natural y la restauración protesica/conservativa es compleja y se basa en dos expedientes principales: la elección del color y su exacta reproducción.

2) El espectofotometro Vita Easyshade ha demonstrado una precisión optimal durante medidas repetidas, en comparación a un espetofotometro de laboratorio. Consecuentemente, este instrumnetal puede ser utilizado sea clínicamente sea para efectuar investigaciones *en vitro*.

3) Las indicaciones ofrecida por los productores, para ayudar los técnicos dentales una correspondencia exacta entre el color elegido por el dentista y el manufacto, son limitadas, y no parecen ser suficientes para evitar discrepancias de colores.

4) La escala de colores Vita 3D Master Toothguide ha permitido lograr correspondencias de colores memore con respecto a Vitapan Classical; esto está relacionado con la distribución sistematica de los tonos de color según un gradiente incremental de Valor y Croma.

5) La escala de colores influencia la capacidad de obtener el color de una ceramica. El procedimento de estratificación de la ceramica sobre el metal tiene un papel fundamental en la obtención del color elegido para una restauración.

6) Con respecto a la ceramica Vita VM13, un aumento del espesor de la capa de Base Dentine determina un incremento del Croma. De otro lado, el Croma de una restauración disminuye a la vez que Transpa Dentine y Enamel aumentan. Un espesor mayor de Enamel produce una disminución de la Luminosidad (Valor) y *vice versa*. Con grosores menores, la ceramica demonstra una mejor correspondencia de la Tinta.

7) Según el espesor final de una metalo-ceramica, el grosor de cada capa y la relación entre los varios estratos con diferente opacidad tienen un papel fundamental en la obtención de la mejor correspondencia del color. El técnico dental debería ser capaz de corregir individualmente los parametros del color, para así lograr la tinta deseada.

Direcciones Futuras

La posibilidad de relacionar a la ciencia algo desde siempre considerada una forma de arte es una gran desafío de la Odontología moderna. La obtención de una restauración lo más parecida posible al natural, y que se integre perfectamente con los tejidos bioológicos circumstantes, es un procedimento altamente dependiente de la habilidad del dentista y del técnico dental.

Hoy en día, los espectofotometros disponibles tienen todas las carateristicas necerarias para divenir instrumentales de uso cotidiano. Estos aparatos pueden ser de ayuda para los clínicos con menores experiencia cuando tienen que enfrentarse con la adecuada selección del color, para evitar, o por lo menos disminuir, las discrepancias que pueden ocurrir.

Los fabricantes de sistemas de ceramica deberían proveer planes detallados sobre los metodos de estratificaciones de la porcelana en relación con el espesor final de la restauración, para así permitir la obtención de un color adecuado. Sería muy útil que las ceramicas dentales fueran disponibiles en el mercado incluso en la coloración Vita 3D Master Toothguide.

Investigaciones futuras deberían evaluar la precisión de todos los espectofotometros clínicos presentes en el mercado dental. Así como sería importante estimar la influencia que los espesores de la ceramica y los esquemas de estratificación podrían tener en todos los sistemas de ceramica presentes en el comercio.

Estudios *en vivo* son deseables para validar los resultados de laboratorio obtenidos en esta thesis doctoral, como demonstración del hecho que la medida instrumental del color puede ser tan eficiente cuanto aquella humana, pero tal vez aún más confiable; pero siempre tomando en consideración que el arte es una virtud que pertenece a los seres humanos y no a las maquinas.

6.4 Zusammenfassung, schlussfolgerungen und zukünftige richtungen

Zusammenfassung

Im **Kapitel 1** wurde das Grundprinzip der Studie dargestellt. Die präzise Farbbestimmung ist immer eine der größten Herausforderungen der Zahnheilkunde und der ästhetischen Zahnmedizin gewesen. Aufgrund der großen Varietät der Zahnfarben ist es sehr kompliziert, eine Übereinstimmung zwischen der Farbe der Restauration und der natürlichen Zahnfarbe zu erreichen. Die zwei wichtigsten Aspekte der Farbbestimmung wurden dargestellt. Der Erste ist die Auswahl einer Farbe, die sich harmonisch mit den umgebenden biologischen Geweben integrieren wird, mithilfe eines Farbmusters. Der Zweite ist die präzise Reproduktion dieser Farbe in der Restauration.

Nach einer kurzen Zusammenfassung der wissenschaftlichen Entdeckungen - von der Studien von Newton im 18. Jahrhundert bis zur heutigen CIELab* Klassifikation der Farbe - wurden einige Betrachtungen über die Anwendung des ΔE angestellt, um die Farbe mit den Zahlen zu korrelieren und die Differenz zwischen zwei Farben mit einer Formel auszurechnen, die die Differenz zwischen zwei Farben mit einer Zahl ausdrückt. Auch wenn diese Entdeckung den Begriff der Wissenschaft der Farbe geändert hatte, wurde die Gelegenheit im Rahmen der Zahnmedizin nicht sofort genutzt, die

Farbbestimmung durch dieses neue System zu verbessern, und man stützte sich auf die visuelle Farbbestimmung weiter.

Eine Übersicht der Entwicklung der wichtigsten Farbmuster wurde dargestellt. Die von dem VITA 3D Master Toothguide eingeführte wissenschaftliche Farbverteilung wurde besonders berücksichtigt. Verglichen mit den vorhergehenden Farbmustern wie das Vitapan Classical oder das Ivoclar-Vivadent Chromascop, die nur das Aussehen der natürlichen Gewebe berücksichtigten, hat sie eine systematische Anordnung der Farben im Rahmen des kolorimetrischen Raums der natürlichen Zähne und sie sieht eine objektive numerische Messung der Farbe mittels des kolorimetrischen CIELab*-Ordnung Prinzips voraus.

Weitere Forschung hatte das Ziel, die Diskrepanz der Farbe durch Kolorimeter und Spektrophotometer auf das Minimum zu senken, die abhängig von der visuellen Evaluation war. Eine kurze Beschreibung der Unterschiede zwischen diesen Geräten wurde gemacht. Das VITA Easyshade und seine Entwicklung (VITA Easyshade Compact) und das MHT Spectro Shade Micro wurden besonders berücksichtigt, weil sie die Spektrophotometer sind, die am meisten unter klinischen Bedingungen verwendet werden.

Wie es vorher erklärt wurde, ist der letzte Schritt der Farbbestimmung von der Reproduktion der Farbe in der Restauration dargestellt. Die Faktoren, die die Endfarbe von Keramik-Restaurationen beeinflussen, wurden diskutiert und die Hauptrolle, die von dem Verhältnis zwischen durchscheinenden und opaken

Schichten der Keramik gespielt wird, wurde betont. In der Tat ist eine korrekte Farbbestimmung nicht ausreichend, wenn sie in Zusammenhang mit der Dicke und der Stratifikation-Technik der Restauration nicht gebracht wird.

Daher hatten die Studien, die in dieser Dissertation dargestellt sind, das Ziel, eine komplette Übersicht der Farbbestimmung zu versorgen und es zu erklären, dass die korrekte Farbbestimmung und die präzise Reproduktion der Farbe notwendig sind, um eine natürlich aussehende Restauration zu erreichen.

Im **Kapitel 2** wurde die Wiederholbarkeit der Messungen eines klinischen Spektrophotometers mit einem Labor-Spektrophotometer verglichen. Der erste Schritt der Bewertung der klinischen Anwendung des VITA Easyshade Spektrophotometers war es, seine Zuverlässigkeit festzustellen. Deshalb wurde in der ersten Phase die Wiederholbarkeit der Messungen dieses Geräts erforscht, um einen Vergleich mit dem Laborsgerät Ocean Optics PSD 1000 anzustellen.

Metall-Keramik Proben wurden durch die Stratifikation unterschiedlicher Mengen von durchscheinender und opaker Keramik vorbereitet. Jede Probe wurde fünfmal mit dem Ocean Optics PSD 1000 getestet, dagegen wurde jede Probe fünfmal freihändig und fünfmal mit der an einem „Stand“ befestigten Sonde gemessen, um die Unterschiede zwischen der klinischen (freihändig) und der laboratorischen (befestigte Sonde) Anwendung zu erforschern. Die Wiederholbarkeit des Spektrophotometers wurde mit der Analyse des Koeffizientes von Variation (KV) statistisch ausgewertet.

Die Ergebnisse haben eine ausgezeichnete Wiederholbarkeit der Messungen mit beiden getesteten Geräten gezeigt. Geringere Koeffizienten von Variation (0.002<KV<0.111) wurden mit dem Ocean Optics PSD 1000 gemessen. Das Easyshade hat eine gute Genauigkeit während der wiederholten Messungen weder mit der befestigten Sonde (0<KV<0.022) noch freihändig (0.008<KV<0.913) gezeigt.

Die gute Genauigkeit des klinischen Geräts verglichen mit dem Laborsgerät hat die Möglichkeit entdeckt, dieses Gerät von beiden klinischen und laboratorischen Anwendungen verwenden zu können.

Im **Kapitel 3** wurden die Unterschiede zwischen den Farben von vier Keramik-Systemen und den Farben „A2, A3 und A3.5“ des Vitapan Classical Farbmusters untersucht. Ein wichtiger Grund der Variabilität der Farbe ist von der Dicke der Keramik dargestellt, weil verschiedene Schichte von Keramik notwendig sind und zwar Opak, Dentin und Schmelz. Angesichts der begrenzten Information aus den Firmen und aus der Literatur über die ideale Proportionen von Dentin und Schmelz war es das Ziel dieser Studie, die Fähigkeit der getesteten Keramik-Systemen zu untersuchen, die ausgewählte Farbe mit den Stratifikation-Hinweisen der Firma zu reproduzieren.

In dieser Studie wurde die Farbe von Metall-Keramik Scheiben mit dem VITA Easyshade klinischen Spektrophotometer gemessen. Drei verschiedene Farben (A2, A3, A3.5) von vier Keramik-Systemen (VITA Omega 900, Duceram Kiss, Wieland Reflex und Ivoclar IPS d.SIGN) mit insgesamt 12 Kombinationen wurden getestet. In jeder Gruppe wurden drei Proben vorbereitet und in der Studie gab es insgesamt 36 Proben. Die Werte des ΔE variierten zwischen 1.2 und 5.0. Die Farbe A2 wurde mit allen getesteten Keramik-Systemen reproduziert (ΔE≤3.7), die Farbe A3 wurde in den Duceram Kiss und Ivoclar IPS Proben reproduziert und die Farbe A3.5 wurde nur in den VITA Omega 900 Proben erreicht. In den anderen Proben wurde die Farbe nicht erfolgreich reproduziert. Die ANOVA hat keine signifikante Unterschiede zwischen den Keramik-Systemen gezeigt ($P>0.05$). Die One-Way ANOVA hat gezeigt, dass die Farbe der Keramik die Werte des ΔE beeinflusst hat ($P<0.05$).

Abschließend hat diese Studie festgestellt, dass die Hinweise der Firma nicht ausreichend sind, um dem Zahntechniker zu helfen, die ausgewählte Farbe in der Restauration zu reproduzieren.

Im **Kapitel 4** wurden zwei wichtige Faktoren untersucht, die die Farbestimmung beeinflussen: die Farbmuster und das Keramik-System. Im **Paragraph 4.1** wurde die Fähigkeit des VITA Omega 900 Keramik-Systems erforscht, die ausgewählte Farbe mit den Vitapan Classical und VITA 3D-Master Toothguide Farbmustern als Referenzen zu reproduzieren. Das VITA Omega 900 wurde in dieser Studie getestet, weil es das einzige Keramik-System war, das es weder in den Farben des Vitapan Classical noch in den Farben des VITA 3D-Master Toothguide gab, als die Studie durchgeführt wurde. Heutzutage wird auch das VITA VM13 weder in den Farben des Vitapan Classical noch in den Farben des VITA 3D-Master Toothguide produziert. Fünfzehn Keramik-Scheiben wurden mit verschiedenen Stratifikation-Techniken mit jeder Farbe (A3 und 2M3) vorbereitet und die Dicke der Proben war konstant. Drei verschiedene Stratifikation-Techniken wurden verwendet, die sich in der Dicke des opaken Dentins, des Dentins und des Schmelzes voneinander unterschieden, um eine Variabilität in dem Ablesen der Farbe zu erreichen. Die Messungen der Farbe wurden mit dem Easyshade in der „Restoration“ Modalität mit den A3 und 2M3 Farben als Referenzen gemacht. Die Two-Way ANOVA hat gezeigt, dass weder die Interaktion „Farbmuster - Keramik-System“ noch der Faktor „Stratifikation-Technik“ die Werte des ΔE signifikant beeinflusst haben ($p<0.001$). Die Proben des VITA Omega 900 in den Farben des VITA 3D-Master Toothguide haben eine bessere Übereinstimmung der Farbe als die Proben des gleichen Keramik-Systems in den Farben des Vitapan Classical gezeigt. Dieses Ergebnis kann man erklären, weil das Easyshade die Farben besser identifizieren kann, die in einer wissenschaftlich-basierten systematischen räumlichen Verteilung organisiert sind.

Deshalb lässt es sich sagen, dass die Übereinstimmung der Farbe von dem Farbmuster abhängig ist. Außerdem wird die Reproduktion der Farbe von der Stratifikation-Technik der Keramik beeinflusst.

Nachdem es festgestellt wurde, dass das VITA 3D-Master Toothguide erlaubt, eine präzisere Übereinstimmung der Farbe zu erreichen, wurde die Fähigkeit von zwei Keramik-Systemen (VITA Omega 900 und VITA VM13) im **Paragraph 4.2** untersucht, die ausgewählte Farbe mit dem VITA 3D-Master Toothguide als Referenz zu reproduzieren, um es festzustellen, ob die Übereinstimmung der

Farbe von dem Farbmuster oder von dem Keramik-System abhängig ist. Das Experiment wurde mit der gleichen Methode der vorhergehenden Studie durchgeführt. Fünfzehn Keramik-Scheiben von jedem Keramik-System wurden mit verschiedener Dicke der Schichten in der Farbe 2M3 vorbereitet. Die mit dem ΔE ausgedrückte Genauigkeit der Farbe wurde mit dem VITA Easyshade getestet. Die Two-Way ANOVA hat gezeigt, dass der Faktor „Keramik-System“ nicht signifikant war ($p=0.17$). Dagegen hat der Faktor „Stratifikation-Technik“ die Werte des ΔE signifikant beeinflusst ($p<0.001$). Alle Proben haben Werte des ΔE geringer als 3.3 gezeigt. Auch wenn ein solches Ergebnis von erfahrenen Fachleuten geschätzt wird, wird es aber unter klinischen Bedingungen für akzeptabel gehalten.

Wenn die Metall-Keramik Proben mit den auf dem VITA 3D-Master Toothguide basierten Keramik-Systemen vorbereitet wurden, gab es keine Unterschiede zwischen VITA Omega 900 und VITA VM13 in ihrer Fähigkeit, die ausgewählte Farbe zu reproduzieren. Dieses Ergebnis zeigte, dass die Übereinstimmung zwischen der Farbe der untersuchten Keramik-Systemen und einer ausgewählten Farbe von dem Farbmuster abhängig ist. Diese Studie hat bestätigt, dass die Stratifikation-Technik der Keramik auf das Metall eine Hauptrolle spielt, um die ausgewählte Farbe in der Restauration zu reproduzieren.

Dieses Ergebnis hat den relativen Einfluss jeder Keramik-Schicht (Base Dentine, Transpa Dentine und Enamel) auf die drei Farbdimensionen (Helligkeit, Intensität und Farbton) der Restauration festgestellt. Dieses Thema wurde im **Kapitel 5** weiterentwickelt. Vierzig Keramik-Scheiben wurden in einer Form aus Stahl vorbereitet und die Dicke jeder Schicht wurde mit einer digitalen Lehre gemessen. Vier verschiedene Dicken der Keramik in der Farbe 2M3 wurden getestet. Für jede Dicke wurden zwei verschiedene Stratifikation-Techniken untersucht. Der klinische Spektrophotometer Easyshade wurde verwendet, um die gemessene Farbe der Proben mit den in dem Farbmessgerät gespeicherten Referenz-Daten zu vergleichen. Die One-Way ANOVA zeigte, dass der Faktor „Stratifikation-Technik“ die ΔE, ΔC, ΔH und ΔL signifikant beeinflusste ($p<0.001$). Eine größere Dicke des Base Dentine verursachte die Erhöhung der Intensität. Dagegen verursachte eine größere Dicke des Transpa Dentin und des Enamel eine Senkung der Intensität. Mit einer erhöhten Dicke der Enamel Schicht gab es die Senkung der Helligkeit und umgekehrt. Eine präzisere Übereinstimmung des Farbtons wurde mit geringeren Dicken erreicht.

Hängt die endgültige Dicke der PFM Restauration ab, spielen die Dicke jeder Schicht und das Verhältnis zwischen den Schichten eine Hauptrolle, um die beste Übereinstimmung der Farbe zu erreichen. Der Zahntechniker muss die Farbdimensionen individuell adaptieren, um eine bestimmte Farbe zu reproduzieren.

Schlussfolgerungen

Unter Berücksichtigung von den Grenzen der vorhergehenden Studien, können die folgende Schlussfolgerungen aus unserer Bestimmung der Faktoren, die die Übereinstimmung der Farbe beeinflussen, gezogen werden.

1) Das Verfahren, um die Übereinstimmung zwischen den natürlichen Zahnfarben und der Restauration zu erreichen, ist sehr komplex und es besteht aus zwei Phasen: die Farbestimmung und die Reproduktion der Farbe.
2) Der klinische Spektrophotometer VITA Easyshade hat eine gute Genauigkeit, verglichen mit einem Laborsgerät, wenn er für wiederholte Messungen verwendet wird. Daher kann dieses Farbmessgerät weder in der Praxis noch im Labor verwendet werden.
3) Die Hinweise der Keramik-Firmen sind begrenzt und nicht ausreichend, um den Zahntechnikern zu helfen, die Übereinstimmung zwischen der ausgewählten Farbe und der Endrestauration zu erreichen und Fehler zu vermeiden.
4) Verglichen mit dem Vitapan Classical Farbmuster, hat das VITA 3D-Master Toothguide eine bessere Übereinstimmung der Farbe dank seiner systematischen Verteilung von „Tabs“ nach einem steigenden Gradient der Helligkeit und der Intensität gezeigt.

5) Die Übereinstimmung der Farbe der Restauration mit einer ausgewählten Farbe hängt von dem Farbmuster ab. Die Stratifikation-Technik der Keramik auf das Metall spielt eine Hauptrolle, um die ausgewählte Farbe in der Restauration zu reproduzieren.
6) Im Bezug auf dem VITA VM13 verursacht eine größere Dicke des Base Dentine die Erhöhung der Intensität. Dagegen senkt eine größere Dicke des Transpa Dentin und des Enamel die Intensität der Farbe. Eine Erhöhung der Dicke der Enamel Schicht verursacht die Senkung der Helligkeit (Value) und umgekehrt. Eine präzisere Übereinstimmung des Farbtons wurde mit geringeren Dicken erreicht.
7) Hängt die endgültige Dicke der PFM Restauration ab, spielen die Dicke jeder Schicht und das Verhältnis zwischen den Schichten eine Hauptrolle, um die beste Übereinstimmung der Farbe zu erreichen. Der Zahntechniker muss die Farbdimensionen individuell adaptieren, um eine bestimmte Farbe zu reproduzieren.

Zukünftige Richtungen

Die Möglichkeit, etwas in Zusammenhang mit der Wissenschaft zu bringen, das für eine Art von Kunst immer gehalten wurde, stellt eine der größten Herausforderungen der modernen Zahnmedizin. Eine Restauration zu erhalten, die natürlich aussieht und die sich harminisch mit den umgebenden biologischen Geweben integriert, wurde immer von den Fähigkeiten des Zahnarztes oder des Zahntechnikers beeinflusst.

Die klinische Spektrophotometer haben die Voraussetzungen, in den zahnärztlichen Praxen zur Routine zu werden. Sie können von unerfahrenen Fachleuten für die Farbestimmung verwendet werden, um eine falsche Übereinstimmung der Farbe zu vermeiden oder zu mindestens zu senken.

Die Keramik-Firmen sollten eine präzise Auskunft über die Stratifikation-Technik geben, die man für ihre Materialien verwenden muss, um die ausgewählte Farbe zu erreichen. Außerdem sollten die Firmen Keramik-Systemen verkaufen, die nach dem VITA 3D-Master produziert werden.

Zukünftige Studien sollten die Genauigkeit anderer Spektrophotometer untersuchen. Der Einfluss der Dicke und der Stratifikation-Technik anderer Keramik-Systemen sollte festgestellt werden.

Klinische Untersuchungen sollten die Labor-Daten bestätigen, um es zu zeigen, dass die instrumentelle Farbestimmung zuverlässiger als die visuelle Evaluation der Farbe ist. Man muss aber immer berücksichtigen, dass die Kunst mit den Menschen und nicht mit den Maschinen zu tun hat.

6.5 Resumé, conclusions and directions futures

Resumé

Dans le **chapitre 1**, le rationnel de cette étude a été présenté. La détermination adéquate de la couleur a toujours été un défi en dentisterie restauratrice et esthétique. La grande variation de couleurs présente dans la dent naturelle rend la concordance de couleur avec les restaurations très complexe. Deux critères majeurs de la technique suivit pour le choix de la teinte ont été présentés. Le premier critère étant la sélection de la couleur, à l'aide d'un teintier, qui va assurer une intégration harmonieuse avec les tissus biologiques avoisinants et le deuxième critère étant la reproduction correcte de cette couleur au niveau de la restauration prothétique.

Apres un bref résumé des découvertes scientifique de Newton au 18^{iem} siècle à la classification de couleur utilisant le CIELab*, quelques modifications ont été réalisées afin de pouvoir faire une corrélation numérique de la couleur avec l'utilisation de ΔE et le calcul de la différence entre les deux couleurs en utilisant une formule qui donne une valeur pour cette différence. Même si l'importance de cette découverte a changé le concept de la science de la couleur, la pratique dentaire quotidienne n'a pas saisi cette occasion pour améliorer la concordance de couleur et l'évaluation visuelle demeure la règle suivie.

Une revue critique de l’évolution des teintiers a été présentée avec une attention spéciale envers le teintier VITA 3D Master quant à la distribution scientifique de la couleur. Il représente un arrangement systématique des couleurs dans l’espace naturel de la dent ainsi qu’une mesure numérique de la couleur, en accord avec le principe colorimétrique CIELab*, et donne un meilleur résultat que l’observation classique des teintiers comme Vitapan classic ou Chromascop Ivoclar-Vivadent.

Des recherches sur l’utilisation des colorimètres et spectrophotomètres, afin de minimiser la discordance de la couleur causée par l’estimation visuelle ont été réalisées. Une description brève sur la différence entre ces instruments a été présentée. Une attention particulière envers les colorimètres Vita Easyshade et Vita Easyshade Compact ainsi que le MHT Spectro Shade Micro, car ces spectrophotomètres sont les plus utilisés dans la pratique quotidienne.

Comme déjà cité, l’étape finale dans la concordance de couleur est représentée par la reproduction correcte de la couleur finale de la restauration prothétique. Une discussion brève concernant les facteurs influençant la couleur final des restaurations en céramique a été faite, en particulier le rôle important de la pose des couches entre les couleurs opaque et transparentes. Même un choix correct de la couleur n'est pas suffisant s'il n'y a pas une corrélation directe entre l'épaisseur et la position de ces deux couches au niveau de la restauration.

Le but de cette thèse est de donner une idée sur la marche à suivre pour la concordance de couleur, et ainsi d'élucider le moyen de réaliser des restaurations naturelles et de monter que le choix de la couleur ainsi que sa reproduction ne sont pas suffisants pour donner un aspect naturel à la restauration.

Dans le **Chapitre 2**, la répétitivité des résultats obtenus à l'aide d'un spectrophotomètre clinique a été comparé avec un autre établit au laboratoire. L'étape initiale est l'évaluation de la fiabilité de l'utilisation clinique du VITA Easyshade spectrophotometer. Pour cette raison, la première phase a consisté à évaluer la répétitivité des mesures enregistrées par la machine, comme condition requise pour évaluer sa performance en comparant avec un spectrophotomètre de laboratoire l'Ocean Optics PSD 1000 en l'occurrence

Des échantillons de métal recouvert par de la céramique ont été confectionnés en différentes épaisseurs d'opaque et de couche de transparent afin de mesurer la répétitivité. L'Ocean Optics PSD 1000 a été utilisé pour mesurer les valeurs de la couleur de chaque échantillon à 5 reprises, tandis que pour le VITA Easyshade les mesures ont été répétées 5 fois a main levée et 5 fois en le fixant à une base, pour pouvoir comparer la différence existante entre l'utilisation Clinique (main libre) et l'utilisation au laboratoire (fixé à une base). La répétitivité du spectrophotometer a été statistiquement évaluée en analysant le Coefficient de Variation (CV).

Les résultats ont montré une excellente répétitivité pour les 2 instruments étudiés. Des valeurs faibles du coefficient de variation

(0,002<CV<0,111) ont été obtenues avec Ocean Optics PSD 1000. Easyshade a démontré une bonne précision dans la numérisation répétitive obtenu en fixant la pièce a main de l'instrument à une base (0<CV<0,022) ou à main libre (0,008<CV<0,913).

La comparaison de la précision et de la fidélité des instruments cliniques comparés a ceux du laboratoire, a montré une répétitivité des mesures révélant la possibilité de les utiliser en clinique et au laboratoire.

Dans le **Chapitre 3**, les variations de couleur entre quatre systèmes de céramique dentaire et les teintes sélectionnées "A2, A3 and A3.5" du teintier Vitapan Classical ont été évaluées. Une source importante de la variation de couleur est représentée par l'épaisseur de la céramique, par le besoin d'avoir des couches différentes de céramique comme l'opaque, la dentine ou l'email. A cause de la limitation des informations obtenues des fabricants ou au niveau la littérature à propos des proportions idéales de dentine et d'email, l'objective de cette étude a été de vérifier si tous les systèmes de céramique étudiés ont été capable de reproduire correctement la couleur choisie suivant le diagramme d'application par couche décrit dans les instructions du fabricant.

Cette étude a été réalisée en analysant la correspondance de couleur des disques metalo-ceramique en utilisant le VITA Easyshade spectrophotometer. Trois teintes différentes (A2, A3, A3.5) de quatre systèmes de céramique (VITA Omega 900, Duceram Kiss, Wieland Reflex and Ivoclar IPS d.SIGN) ont été étudiés résultant en un total de

12 combinaisons. Pour chaque groupe, 3 échantillons ont été fabriqués, donc un total de 36 échantillons. Les valeurs de ΔE ont variés entre 1.2 and 5.0. La correspondance clinique de la couleur (ΔE ≤ 3.7) a été enregistre pour la teinte A2 pour tout les systèmes de céramique, quant à la teinte A3 des échantillons de Duceram Kiss et Ivoclar IPS et la teinte A3.5 uniquement pour les échantillons VITA Omega 900. Tous les autres échantillons ont échoué dans la correspondance de la couleur. L'analyse ANOVA a montré que la teinte de la céramique influence de façon significative les valeurs ΔE (P<0.05).

En conclusion, cette étude a montré que les instructions données par le fabriquant pour aider le technicien de laboratoire à obtenir la meilleur concordance de couleur entre la teinte choisie et la teinte de la restauration finale étaient très limitées et insuffisante pour éviter une discordance de couleurs.

Dans le **Chapitre 4** deux facteurs importants qui affectent la concordance de la couleur ont été évalués: l'influence du teintier et l'influence du système de céramique. Dans le **paragraphe 4.1** la capacité du VITA Omega 900 de reproduire correctement la couleur choisie en se référant aux teintiers Vitapan Classical et VITA 3-D Master a été testée. VITA Omega 900 a été choisi car il était le seul système de céramique commercialisé avec les teintiers Vitapan Classical et VITA 3D-Master. Quinze disques en céramique ont été fabriqués suivant des modèles de pose de différentes couches d'opaque et de céramique pour chaque teinte (A3 and 2M3), tout en gardant une épaisseur uniforme et constante pour tous les échantillons. Trois modèles distincts ont été réalisés avec une variation de l'épaisseur des couches opaques, dentine et email, dans le but de créer une variabilité dans la lecture de la couleur. L'évaluation de la couleur a été réalisée avec le Easyshade et le mode "restoration" a ete sélectionné en utilisant les teintes A3 et 2M3. Le test Two-Way ANOVA a montré que l'interaction entre le "teintier-système de céramique" et le facteur "épaisseur des couches model" influence de manière significative les valeurs ΔE ($p<0.001$). Les échantillons VITA Omega 900 avec le teintier VITA 3D-Master ont donné pour la teinte testée une couleur plus proche que les échantillons avec la même céramique en combinaison avec le teintier Vitapan Classical. Ce résultat peut être expliqué par la capacité de l'Easyshade de correspondre les couleurs grâce à une distribution spatiale systématique scientifiquement fondée.

Par conséquent, une couleur adéquate peut être considérée dépendante du teintier. De plus, la meilleur correspondance de couleur est influencée par le model de pose des différentes couches de la céramique.

Après avoir établit que grâce au teintier VITA 3D-Master une meilleure concordance de la couleur était obtenue, dans le **paragraph 4.2,** l'étape suivante consistait à examiner la capacité de deux systèmes de céramique (VITA Omega 900 et VITA VM13) de reproduire correctement la teinte choisie en se référant au teintier VITA 3D-Master, pour pouvoir comprendre si la concordance de couleur était dépendante du teintier ou du système de céramique utilisé. Ce test a été effectué en suivant les mêmes méthodes décrites ultérieurement. Quinze disques en céramique ont été réalisés avec des couches d'épaisseurs différentes pour chaque système de céramique en teinte 2M3. La précision de couleur exprimée en ΔE a été évaluée à l'aide du VITA Easyshade. Two-way ANOVA a montré que le facteur "systeme de ceramique" n'était pas statistiquement significatif ($p=0.17$); tandis que le facteur "pose des couches model" influence d'une manière significative les valeurs ΔE ($p<0.001$). Tous les échantillons avaient des valeurs inferieur a 3.3; ce qui est considéré comme sensible pour des operateurs qualifies mais acceptable cliniquement.

Quand les échantillons métallo-céramique ont été fabriqués en se basant sur le teintier VITA 3D-Master, aucune différence n'a été trouvée entre VITA Omega 900 et VITA VM13 quant à leur capacité de correspondre correctement à la teinte choisie. Ces résultats nous amène à dire que pour les systèmes de céramique qui font objet de cette étude, la capacité de concordance de la couleur avec une teinte choisie doit être considérée dépendante du teintier. Une fois de plus cette étude a confirmé que la méthode suivit pour le pose des différentes couches de la céramique sur le métal a un rôle prédominant lors de la réalisation de la teinte sélectionnée pour la restauration.

Ces résultats mettent en évidence l'influence relative de chaque couche de céramique (base dentine, transparent dentine et email) sur les paramètres de la couleur (luminosité, saturation et teinte) des restaurations, qui a été développée dans le chapitre 5. Quarante disques de céramique ont été fabriqués a l'aide d'un moule en métal et inspectés individuellement après la cuisson avec une jauge digitale pour contrôler l'épaisseur de chaque couche. 4 épaisseurs différentes de céramique en teinte 2M3 ont été évaluées. Pour chaque épaisseur, 2 poses de couches différentes ont été analysées. Le Easyshade spectrophotomètre a été utilisé pour comparer la couleur avec comme référence les données de couleur de la teinte sélectionnée à l'aide la machine. One-way ANOVA a montré que le facteur "pose de couche- modèle" influence d'une manière significative le ΔE, ΔC, ΔH et ΔL ($P<0.001$). Une plus grande épaisseur de Base Dentine a entrainé une teinte plus saturée. Inversement, une plus grande épaisseur de transparent Dentine et Email a réduit la saturation de la teinte. Une augmentation de l'épaisseur de la couche d'Email a entrainé une réduction de la luminosité et vice-versa. Une meilleure correspondance de teinte a été obtenue avec des épaisseurs plus réduites

En fonction de l'épaisseur finale de la restauration céramométallique, l'épaisseur individuelle de chaque couche et le rapport entre les couches jouent un rôle important dans la réalisation de la meilleure correspondance de couleur. Le technicien doit être capable d'ajuster personnellement les paramètres de couleur dans le but d'obtenir une teinte bien déterminée.

Conclusions

Dans les limites de cette étude, les conclusions suivantes peuvent être établies en évaluant les facteurs influençant la technique de correspondance de la couleur:

1) La réalisation de la correspondance de la couleur entre la dentition naturelle et la restauration ou prothèse est un procédé complexe qui se fait en deux étapes: sélection de la couleur et reproduction de la couleur.
2) VITA Easyshade spectrophotometre a révélé une bonne précision, comparable à l'instrument de laboratoire, en effectuant des mesures répétées. Ceci veut dit que l'instrument peut être utilisé comme instrument de routine au cabinet dentaire et pour test in-vitro.
3) Les indications données par les fabricants de céramique pour aider les techniciens à obtenir une correspondance de la couleur entre la teinte sélectionnée et la restauration finale sont très limitées, et pas suffisante pour éviter une marge d'erreur.
4) Le teintier VITA 3D-Master a entrainé une concordance de couleur supérieure au teintier Vitapan Classical, à cause de la distribution systématique des teintes en accord avec un gradient croissant de luminosité et de saturation.
5) La capacité de concordance de la couleur doit être considérée comme dépendante du teintier. L'approche adoptée pour la

pose des différentes couches de la céramique sur du métal a un rôle prédominant dans la réalisation des teintes sélectionnées pour la restauration.

6) En ce qui concerne VITA VM13, une épaisseur supérieure de dentine a entrainé une teinte plus saturée. Inversement, une plus grande épaisseur de Transparent Dentine et Email a réduit la saturation de la teinte. Une augmentation de l'épaisseur de la couche d'Email a entrainé une réduction de la luminosité et vice-versa. Une meilleure correspondance de teinte a été obtenue avec des épaisseurs plus réduites.
7) En fonction de l'épaisseur finale de la restauration céramométallique, l'épaisseur individuelle de chaque couche et le rapport entre les couches jouent un rôle important dans la réalisation de la meilleure correspondance de couleur. Le technicien doit être capable d'ajuster personnellement les paramètres de couleur dans le but d'obtenir une teinte déterminée.

Directions Futures

La possibilité de faire relever de la science quelque chose qui a de tout temps été considéré une forme d'art représente un des plus grand défis de la dentisterie moderne. La réalisation de restauration avec un aspect naturel qui s'intègre correctement avec les tissues biologiques a toujours été influencée par les qualifications du clinicien et du technicien.

Les spectrophotomètres cliniques ont la capacité d'être utilisés en routine au cabinet dentaire. Ils peuvent être utilisés pour aider des cliniciens avec une moindre expérience d'arriver à une concordance de la couleur et ce dans le but d'éviter et de réduire le décalage de couleur.

Les fabricants de céramique doivent fournir des étapes spécifiques quand a la technique de pose des différentes couches de la céramique en relation avec l'épaisseur final de la restauration en vue d'obtenir la teinte souhaitée.

Les fabricants de céramique doivent aussi fournir des systèmes commercialisés suivant le teintier VITA 3D-Master.

Des études futures doivent évaluer la précision d'autres spectrophotomètres cliniques commercialisés. L'influence de l'épaisseur et des étapes de pose des différentes couches doivent être évaluées pour d'autres systèmes de céramique.

Des études cliniques sont nécessaires pour confirmer les données de laboratoire, dans le but de prouver que le choix de la couleur à l'aide d'un instrument peur être aussi efficace que le choix humain mais plus fiable tout en considérant toujours que cet art est lié à l’être humain et non pas a des machines.

6.6 Resumo, conclusões e futuras investigações

Resumo

No **Capítulo 1**, a razão do presente estudo foi apresentada. Coincidir a precisa matiz sempre foi um dos aspectos mais desafiadores da restauração de dentes e odontologia estética em geral. Devido à grande variedade de cor natural dos dentes, conseguindo um jogo de matiz perto de uma restauração artificial com dentição natural continua a ser um processo complexo. Dois aspectos principais das cores correspondentes processos foram apresentados. Um deles é a seleção de uma cor, através de um guia de cores, que vai integrar-se harmoniosamente com os tecidos circundantes biológicos e a outra é a reprodução correta desta cor em prótese ou restauração. Depois de um breve resumo das descobertas científicas a partir de experimentos de Newton no século 18 com a classificação de cor CIELab *, algumas considerações foram feitas sobre o uso de \ Delta correlacionando as cores numericamente e, finalmente, calcular as diferenças entre as duas cores usando uma fórmula que dá um número como o valor das diferenças de cor. Embora a importância deste achado ter mudado o conceito de ciência da cor, prática odontológica esta oportunidade de melhorar a capacidade de combinação de cores e avaliação visual manteve-se o processo de referência.

Uma análise crítica da evolução do simulador de cor mais importante foi apresentado. Especial atenção foi dada à distribuição de cor científica introduzida pela VITA 3D Master Toothguide. O qual tem um arranjo sistemático de máscaras dentro do espaço de cor natural do dente e uma medida objetiva numérico de cor, de acordo com o princípio colorimétrico fim CIELab *, mais do que a simples observação dos aspectos tecido natural pertencente ao guia de cores anteriores, como Vitapan clássica ou Ivoclar-Vivadent Chromascop.

O objetivo adicional de investigação de minimizar a incompatibilidade de cor devido à estimativa visual, utilizando-se um colorímetro e espectrofotômetros. Uma breve descrição das diferenças entre estes instrumentos foi fornecida. Particular atenção tem sido focada em VITA Easyshade e sua evolução (VITA Easyshade Compact) e MHT Spectro Shade Micro, que estes instrumentos são dois dos espectrofotômetros mais usados rotineiramente clínica.

Como anteriormente apresentado, na última etapa em processos de cor correspondente é representado pela reprodução de cor correta na prótese ou restauração. Uma breve discussão sobre os fatores que influenciam a cor final de restaurações de porcelana foi dada, destacando especialmente o papel preponderante desempenhado pela relação entre camadas de tons opacos e translúcidos.

Até mesmo uma seleção de tonalidade correta não é suficiente se não há nenhuma correlação com a espessura e estratificação da restauração.

Portanto, o trabalho descrito nesta tese teve como objetivo proporcionar uma visão sobre a cor correspondente ao procedimento odontológico, bem como para elucidar a realização de uma aparência natural, a restauração não pode prescindir de uma seleção correta da cor seguida por sua reprodução exata.

No **Capítulo 2**, a repetição da medição de um espectrofotômetro clínico foi comparada com um de laboratório . O passo inicial na avaliação do uso clínico do espectrofotómetro Easyshade VITA dental foi considerar a sua precisão. Por esta razão, a primeira fase foi avaliar a repetição das medições efetuadas pelo instrumento, como um requisito obrigatório para avaliar a performance em comparação com a da Ocean Optics PSD 1000, como um instrumento de laboratório .

Espécimes de metalo cerâmica em camadas de acordo com diferentes quantidades de porcelanas opacos e translúcidos foram fabricados a fim de realizar medidas repetidas. The Ocean Optics PSD1000 foi testada medindo os valores de cor de cada amostra 5 vezes, enquanto que para VITA Easyshade as medições foram repetidas 5 vezes a mão livre e 5 vezes a fixação da sonda de medição de um stand, a fim de testar se havia diferenças entre uso clínico (mão livre) ou de laboratório (uso fixo a um suporte). A reprodutibilidade utilizando o espectrofotômetro foi avaliada estatisticamente pela análise do Coeficiente de Variação (CV).

Os resultados demonstraram uma excelente reprodutibilidade de varredura para ambos os instrumentos testados. Valores muito baixos de coeficiente de variação (0.002 <CV <0.111) foram obtidos para o Ocean Optics PSD1000. O Easyshade mostrou boa precisão na digitalização repetida obtidos tanto através da fixação da peça de mão do dispositivo de um stand (0 <CV <0.022) e à mão livre (0.008 <CV <0.913).

A boa precisão mostrada pelos instrumentos clínicos, em comparação com um laboratório, na realização de medidas repetidas revelou a possibilidade de usá-lo tanto para uso clínico e de testes in vitro.

No **Capítulo 3**, as variações de cor entre quatro sistemas de porcelana dentária e as máscaras controle "A2, A3 e A3.5" de croma do guia Vitapan Classical foram investigados. Uma importante fonte de variação da cor é representada pela espessura de porcelana, pela necessidade de ter diferentes camadas de porcelana, como opaco, dentina e esmalte. Considerando as informações muito limitadas pelos fabricantes, ou da literatura, em que a proporção ideal de esmalte e dentina devem ser, o objeto do presente estudo foi verificar se todos os sistemas cerâmicos testados foram capazes de corresponder exatamente à matizes selecionadas na seqüência de diagramas de camadas relatado nas instruções dos fabricantes.

Este estudo foi realizado através da avaliação da correspondência de cores do disco de porcelana em forma de restaurações metálicas fundidas, utilizando o espectrofotômetro VITA Easyshade. Três diferentes tonalidades (A2, A3, A3.5) para quatro diferentes sistemas de cerâmica (Vita Omega 900, Duceram Kiss, Wieland Reflex e Ivoclar IPS d.SIGN) foram investigados, resultando em um total de 12 combinações. Para cada grupo, três amostras foram confeccionadas para um total de 36 exemplares. \ Delta de valores variaram entre 1,2 e 5,0. Coincidindo Shade clínica (\ Delta ≤ 3,7) foi registrada para A2 em todos os sistemas de cerâmica, para A3 em Duceram Kiss e espécimes Ivoclar IPS e para A 3.5 apenas nos espécimes da Vita Omega 900. Todas as outras amostras não conseguiram atingir correspondência de cor. Análise de variância não mostrou diferenças estatisticamente significativas (P> 0,05) entre as marcas de porcelana. One-way ANOVA mostrou que o croma de cerâmica influenciou significativamente os valores de DE (P <0,05).

Em conclusão, este estudo mostrou que as orientações fornecidas pelo fabricante para ajudar o técnico a obter a correspondência de cor entre os cromas selecionados e a restauração final, é muito limitado, e não suficiente para evitar incompatibilidade de cor.

No **Capítulo 4**, dois fatores importantes que afetam o jogo de matiz foram investigadas: a influência do guia de cores e da influência do sistema de cerâmica. No **Ponto 4.1** a capacidade de Vita Omega 900 de cerâmica para reproduzir corretamente a cor de sombra selecionado com referência ao Vitapan Classical e VITA 3D-Master Toothguide foi testado. Vita Omega 900 foi objeto deste estudo, porque era, no momento do teste, o único sistema de cerâmica dental comercializado no guia de cores Vitapan Classical, bem como no VITA 3D-Master Toothguide. Hoje, mesmo VITA VM13 é comercializado tanto no Vitapan Classical e VITA 3D-Master Toothguide. Quinze discos de cerâmica foram fabricados com diferentes padrões de estratificação para cada croma (A3 e 2M3), mantendo-se constante a espessura da amostra total. Três padrões de camadas distintas que diferem de acordo com a espessura da dentina opaca, dentina, e as camadas de esmalte, a fim de criar uma variabilidade na leitura de cor. A avaliação da cor foi feita com o Easyshade e "Modo de Restauração" foram selecionados através de A3 e 2M3 para comparação. O Two-way ANOVA mostrou que tanto a interação do "guia de tonalidades sistema de cerâmica" e o fator "camadas" padrão influenciou significativamente os valores de DE (p <0.001). Espécimes de Vita Omega 900 no VITA 3D-Master Toothguide exibido pela croma investigado uma maior adaptação na cor do que espécimes do mesmo sistema de cerâmica no guia de cores Vitapan Classical. Este resultado pode ser explicado pela capacidade de Easyshade melhor corresponder às cores que são organizados em uma base científica sistemática de distribuição espacial.

Portanto, a correspondência de cor mais alta pode ser considerada como guia de cores dependentes. Além disso, a melhor cor para combinar resultou ser influenciada a partir do padrão selecionado para porcelana camadas procedimento.

Depois de estabelecer que o VITA 3D-Master Toothguide resultou em melhor padrao de cores, no **Ponto 4.2**, a próxima etapa analisou a capacidade de dois materiais dentários de porcelana (Vita Omega 900 e VITA VM13) reproduzirem corretamente a cor selecionada com referência a VITA 3D-Master Toothguide, a fim de compreender a fidelidade do guia de tonalidades de cor dependente ou cerâmica sistema dependente. O teste foi realizado após os mesmos métodos que a anterior. Quinze discos de cerâmica foram produzidos com espessuras diferentes para cada sistema de cerâmica em 2M3. A precisão de cores expresso em \ Delta foi testada com o Easyshade VITA. Dois testes ANOVA mostraram que o fator "sistema de cerâmica" não foi estatisticamente significativo (p = 0,17), enquanto que o fator "camadas" padrão influenciou significativamente os valores de DE (p <0,001). Todas as amostras apresentaram valores abaixo de 3,3 \ Delta, que é considerado sensível por parte dos operadores qualificados, mas clinicamente aceitável.

Quando as amostras de cerâmica / metal ter sido fabricado com sistemas baseados em cerâmica VITA 3D-Master Toothguide, não foram encontradas diferenças entre Vita Omega 900 e VITA VM13 na sua capacidade de corresponder corretamente ao tom desejado. Esse achado sugere que, para os sistemas cerâmicos deste estudo, a capacidade de combinar a cor com um tom desejado teve de ser considerado dependente do guia de tonalidades. Uma vez mais, este estudo confirmou que o esquema seguido para a estratificação da porcelana sobre o metal teve um papel preponderante na realização da cor escolhida para a restauração.

Tal conclusão estabelece a influência relativa de cada camada da porcelana (Base de dentina, topo da dentina e esmalte) sobre os parâmetros de cor (Valor, Matiz e Chroma) das restaurações, que foi desenvolvido no **Capítulo 5**. Quarenta discos de cerâmica foram fabricados com um molde de aço de propriedade e controlados individualmente, após a queima um paquímetro digital foi usado para controlar a espessura de cada camada. 4 diferentes espessuras totais de cerâmica na 2M3 foram avaliados. Para cada espessura, 2 padrões de camadas diferentes foram analisados. O espectrofotômetro Easyshade clínico foi usado para comparação de cor com os dados de referência de cor selecionadas e armazenado no dispositivo. One-way ANOVA mostrou que o fator "mergulhar" influenciou significativamente o \ Delta, ΔC, ΔH e ΔL ($p <0{,}001$). Grande espessura da dentina Base resultou em um tom mais cromático. Inversamente, Espessuras maiores de corpo de dentina e esmalte reduziram o croma da cor. Um aumento na espessura da camada de esmalte resultou em uma redução da luminosidade (valor) e vice-versa. Uma análise de correspondência em Matiz, foi obtida com espessuras menores.

Dependendo da espessura final da restauração da GFP, a espessura individual de cada camada e a relação entre as camadas desempenham um papel importante na construção do melhor jogo de cores. O técnico tem de ser capaz de ajustar individualmente os parâmetros de cor a fim de atingir certo tom.

Conclusões

Dentro das limitações dos estudos, as seguintes conclusões podem ser tiradas da nossa avaliação dos fatores que influenciam a cor correspondente ao procedimento odontológico:

1) Conseguir uma correspondência entre a cor correta da dentição natural e restauração ou prótese é um processo complexo que consiste em dois procedimentos específicos: seleção de cor e reprodução de cor.
2) Espectrofotômetro clínico VITA Easyshade revelou boa acurácia, comparável a um dispositivo de laboratório, na realização de medições repetidas. Isso significa que o dispositivo pode ser usado clinicamente como um instrumento de rotina de escritório e de ensaios in vitro.
3) As indicações dos fabricantes de cerâmica para ajudar os técnicos a obter o jogo de cores entre a cor selecionada e a restauração final são muito limitadas, e não suficiente para evitar incompatibilidade de cor.
4) VITA 3D-Master Toothguide resultou em uma correspondência de cor maior quando considerada com guia de cores Vitapan Classical, graças à sua sistemática de distribuição de guias de acordo com um gradiente crescente de valor e Chroma.
5) A capacidade de combinar a cor com um tom desejado tem de ser considerado dependente do guia de tonalidades. A abordagem adotada para a estratificação da porcelana sobre o

metal tem um papel preponderante na realização da cor escolhida para a restauração.

6) No que diz respeito VITA VM13, uma maior espessura da dentina Base resultou em um tom mais cromático. Inversamente, Transpa em espessuras maiores de dentina e esmalte reduziram o croma da cor. Um aumento na espessura da camada de esmalte resultou em uma redução da luminosidade (valor) e vice-versa. Uma análise de correspondência em valor, foi obtida com espessuras menores.
7) Dependendo da espessura final da restauração cerâmica / metal, a espessura individual de cada camada e a relação entre as camadas desempenham um papel importante na confecção do melhor da combinações de cores. O técnico tem de ser capaz de ajustar individualmente os parâmetros de cor a fim de atingir certo tom.

Futuras Investigações

A possibilidade de se relacionar com algo que a ciência sempre foi considerada uma forma de arte representa um dos maiores desafios na odontologia moderna. Conseguir uma aparência natural restauração que se integra corretamente com o tecido biológico foi sempre influenciada pela habilidade do odontologo ou técnico.

Espectrofotômetros clínicos têm a capacidade de tornar-se utilizados rotineiramente como equipamentos de escritório. Estes podem ser usados para ajudar os clínicos menos experientes na seleção da cor correspondente nos procedimentos a fim de evitar ou pelo menos reduzir a incompatibilidade de cores.

Fabricantes de cerâmica deveram criar mecanismos específicos sobre como a sua camada de material de porcelana relativas à espessura final da restauração, a fim de obter a tonalidade desejada. Fabricantes de cerâmica também devem fornecer sistemas comercializados de acordo com a VITA 3D-Master Toothguide.

Experimentos futuros deverão avaliar a exatidão de outros comercializados espectrofotômetros clínica. A influência da espessura e dos esquemas de estratificação deve ser avaliada para outros sistemas de cerâmica.

Os estudos clínicos são necessários para suportar os dados do laboratório, a fim de fazer prova de que a detecção de cor pode ser tão eficiente quanto um ser humano, mas mais confiável, sempre considerando que a arte é algo relacionado com os seres humanos e não máquinas.

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