REPEATABILITY OF COLOUR READING WITH A CLINICAL AND A LABORATORY SPECTROPHOTOMETER

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Abstract

Objectives: The aim of this study was to evaluate the repeatability of readings with a clinical spectrophotometer in comparison with a laboratory one.

Materials and Methods: A stand alone clinical spectrophotometer (Easyshade, Vita) and a laboratory one (PSD1000, Ocean Optics) were evaluated. Five ceramic disks were produced in different layering, with a fixed total thickness of the samples being maintained. Metal disks of 15mm in diameter and 0.7mm thickness were cast. The ceramic system used for layering was Omega 900 (Vita), and the colour selected for the trial was A3. The colour evaluation of each sample was repeated 5 times with each spectrophotometer to verify the scanning repeatability. The spectrophotometer repeatability was statistically evaluated analyzing the coefficient of variation (CV), which represents the ratio of the standard deviation to the mean of the CIELab* colour values.

Results: An excellent scanning repeatability for both the spectrophotometers tested was demonstrated. Very low values of the coefficient of variation (0,002<CV<0,111) were obtained for Ocean Optics PSD1000 as well as for Easyshade, by both fixing the handpiece of the device to a graded stand (0<CV<0,022) and holding it by hand (0,008<CV<0,913).

Discussion: Although manufacturing differences do not allow a direct comparison to be made between the two instruments tested, the reading values obtained from the tests showed an excellent scanning repeatability, both for the clinical spectrophotometer (Easyshade) and for the laboratory one (PSD1000).

Conclusions: The repeatability of the readings with the clinical device were acceptable and comparable to the laboratory one and it can therefore be considered reliable. However, further studies are necessary to verify the exact connection between the colour values obtained from the clinical spectrophotometer and the absolute CIELab* values specific for each shade.

Clinical significance: the high level of repeatability obtained with the clinical spectrophotometer is a promising step forward in the use of an instrument to obtain objective shade selection in clinical circumstances.

Short Title: Repeatability of colour matching determinations.

Key words: Ceramic restoration, colour matching technique, spectrophotometer measurement repeatability.

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[1]. The most common way to evaluate and reproduce natural teeth colour for ceramic restorations 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 the 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 colour reproduction for ceramic restorations[2], 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*, where 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 a value for colour differences[3].

In the late 1990's the CIELab* system was incorporated into

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Table 1. Thickness of the specimens

Sample	Alloy	Opaque	O 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

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[4].

More recently, in order to minimise 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 an easier and more precise transfer and communication of colour in restorative dentistry. This has been a significant step in the development of spectrophotometers[5-11].

The spectrophotometer is a sophisticated instrument, designed to measure an observed object by reflection or transmission, giving the entire spectral curve as a result, limiting colour measurement to a 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 stand alone clinical system and the PSD1000 (Ocean Optics, FL, USA) which 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 ceramic disks were produced in different layering, with a fixed total thickness of the samples being maintained.

0,7mm 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 mould and put into a refractory cast filled with 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 AlO2 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, according to 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 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 mould 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.

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 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 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

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

Scanning	Δ Δ E	Δ C	Δ H	Δ L	ΔE_{LC}	Value
1.a	5,1	-3,6	-2,7	3,5	5,0	Adjust
1.b	5,1	-3,7	-2,7	3,5	5,1	Adjust
1.c	5,2	-3,7	-2,7	3,6	5,2	Adjust
1.d	5,3	-3,8	-2,7	3,6	5,2	Adjust
1.e	5,3	-3,8	-2,7	3,6	5,2	Adjust
$CV_{\#}$	0,0192	0,0225	0	0,0154	0,0174	
2.a	4,3	-2,6	-3,4	3,2	4,1	Fair
2.b	4,3	-2,6	-3,4	3,2	4,1	Fair
2.c	4,3	-2,6	-3,4	3,2	4,2	Fair
2.d	4,3	-2,6	-3,4	3,2	4,1	Fair
2.e	4,3	-2,6	-3,4	3,2	4,1	Fair
$CV_{\#}$	0	0	0	0	0,0109	
3.a	6,1	-4,9	-2,9	3,5	6,1	Adjust
3.b	6,1	-5,0	-2,9	3,5	6,1	Adjust
3.c	6,2	-5,0	-2,9	3,5	6,1	Adjust
3.d	6,2	-5,0	-2,9	3,5	6,1	Adjust
3.e	6,2	-5,0	-3,0	3,5	6,1	Adjust
$CV_{\#}$	0,0089	0,009	0,0153	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
$CV_{\#}$	0,0164	0	0	0	0	

$_{\#}$ Coefficient of Variation

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.

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[12].

The colorimeter is a relatively simple and low-cost instrument designed to measure colour on the basis of three axes or stimuli by way of a 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 a large aperture for measurement. With the evolution of optic fibre technology, dental manufacturers are now able to produce cost-effective

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

Scanning	Δ Δ E	Δ C	Δ H	Δ L	ΔE_{LC}	Value
1.a	4,0	-2,6	-3,0	2,8	3,9	Fair
1.b	3,9	-2,7	-3,1	2,7	3,9	Fair
1.c	3,8	-2,5	-3,0	2,7	3,7	Fair
1.d	3,9	-2,7	-3,1	2,7	3,8	Fair
1.e	3,7	-2,5	-3,1	2,5	3,6	Fair
CV#	0,0295	0,0385	0,0179	0,0409	0,0345	
2.a	3,2	-1,1	-3,7	2,7	2,9	Fair
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	Fair
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	Fair
CV#	0,0441	0,0771	0,0225	0,0517	0,0469	
3.a	5,2	-4,1	-2,5	3,1	5,1	Adjust
3.b	5,4	-4,2	-2,8	3,2	5,3	Adjust
3.c	5,5	-4,4	-2,8	3,2	5,5	Adjust
3.d	5,6	-4,6	-2,5	3,1	5,6	Adjust
3.e	5,6	-4,6	-2,6	3,1	5,6	Adjust
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	

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#	0,0021	0,0941	0,0516	0,0489	0,0145	0,007	0,0052	0,0276
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#	0,0031	0,0995	0,0658	0,0616	0,0197	0,0102	0,0079	0,0394
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#	0,0026	0,1119	0,0471	0,0447	0,0134	0,008	0,0063	0,0253
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#	0,0016	0,0447	0,036	0,0338	0,0093	0,0049	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#	0,0047	0,0854	0,0878	0,0801	0,0252	0,0141	0,0118	0,0488

Coefficient of Variation

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[13].

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 of the instruments in comparison with the performance of the Ocean Optics PSD 1000 as an established lab instrument[14].

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[13].

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 is 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 (ΔE<3=Good, 3<ΔE<5=Fair, ΔE>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, the following 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 intial 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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