Journal of Dentistry 68 (2018) 104–108

Contents lists available at ScienceDirect

Journal of Dentistry

journal homepage: www.elsevier.com/locate/jdent

Full length article

Objective and subjective aesthetic performance of icon® treatment for enamel hypomineralization lesions in young adolescents: A retrospective single center study

Marta Mazur[a], Stephen Westland[b,*], Fabrizio Guerra[a], Denise Corridore[a], Maurizio Vichi[c], Antonello Maruotti[d], Gianna Maria Nardi[a], Livia Ottolenghi[a]

[a] Department of Oral and Maxillo-facial Sciences, "Sapienza" University of Rome, Via Caserta 6, 00161 Rome, Italy
[b] School of Design, University of Leeds, Leeds, United Kingdom
[c] Department of Statistical Sciences, "Sapienza" University of Rome, Piazzale Aldo Moro, 00161 Rome, Italy
[d] Lumsa University, Rome, Italy

ARTICLE INFO

Keywords:
Hypomineralization
Infiltrative technique
Colour
Visual assessment
Enamel

ABSTRACT

Objectives: An evaluation method is proposed to qualitatively and quantitatively evaluate the clinical outcome of the enamel hypomineralization treatment with infiltrative resin in young adolescents. The aesthetic outcome is assessed before and after treatment by visual evaluation using FDI-colour match criteria and by spectrophotometric analysis using the CIEDE2000 colour difference formula. The visual (subjective) results are compared with the spectrophotometric (objective) approach.

Materials and methods: 76 teeth of patients of Sapienza University (Rome, Italy) presenting early caries lesions and/or developmental defect of enamel on the labial surface of clinical crown were subjected to resin infiltration. Three observers evaluated the aesthetic appearance of the teeth before and after treatment using FDI-colour match criteria. The spectrophotometric colour difference between the affected and sound enamel in each tooth was calculated before and after resin infiltration. A correlation between FDI criteria and the calculated CIEDE2000 colour difference (ΔE_{00}) was performed.

Results: Mean FDI scores and ΔE_{00}, evaluated before and after treatment, were large in all sample. A clear correlation was detected between visual inspections and spectrophotometric colour difference of clinical outcomes.

Conclusions: On the basis of the present study results, the aesthetic outcome of resin infiltration proved to be highly effective, both with visual qualitative and spectrophotometric quantitative assessment.

Clinical relevance statement: Hypomineralized enamel colour abnormalities affect patients' quality of life, therefore tissue preservative cosmetic treatments are requested. An evaluation method of resin infiltration clinical outcome by visual evaluation and spectrophotometry is proposed.

1. Introduction

Early Caries Lesions (ECLs), developmental defects of enamel (DDE), traumatic hypomineralization and molar incisal hypomineralization (MIH) are all characterized by enamel hypomineralization [1]. Hypomineralized enamel may involve pre-eruptive or post-eruptive etiologies. The most common pre-eruptive etiologies are fluorosis, coeliac disease and malabsorption disorders, traumatic hypomineralization and MIH, while ECLs are the most common lesions with post-eruptive etiological factors [2]. Clinical management of enamel hypomineralization is challenging and patients with aesthetic concerns more often require tissue preservation and minimally invasive treatment of tooth colour abnormalities.

Until recently, fluoride or caseine phosphopeptide treatments have been used [3,4]. However, the outcomes are often hampered by lack of patient compliance which can be a particular concern with adolescents. Moreover, the aesthetic effect is usually not satisfactory [5]. To overcome these limitations, a new minimally invasive treatment has recently been proposed that utilizes resin infiltration, a product first developed to halt caries in the posterior segment [6]. This treatment

* Corresponding author at: School of Design University of Leeds Woodhouse Lane Leeds LS2 9JT United Kingdom.
E-mail addresses: marta.mazur@uniroma1.it (M. Mazur), s.westland@leeds.ac.uk (S. Westland), fabrizio.guerra@uniroma1.it (F. Guerra), denise.corridore@uniroma1.it (D. Corridore), maurizio.vichi@uniroma1.it (M. Vichi), a.maruotti@lumsa.it (A. Maruotti), profnardi.giannamaria@gmail.com (G.M. Nardi), livia.ottolenghi@uniroma1.it (L. Ottolenghi).

https://doi.org/10.1016/j.jdent.2017.11.001
Received 3 January 2017; Received in revised form 18 September 2017; Accepted 1 November 2017

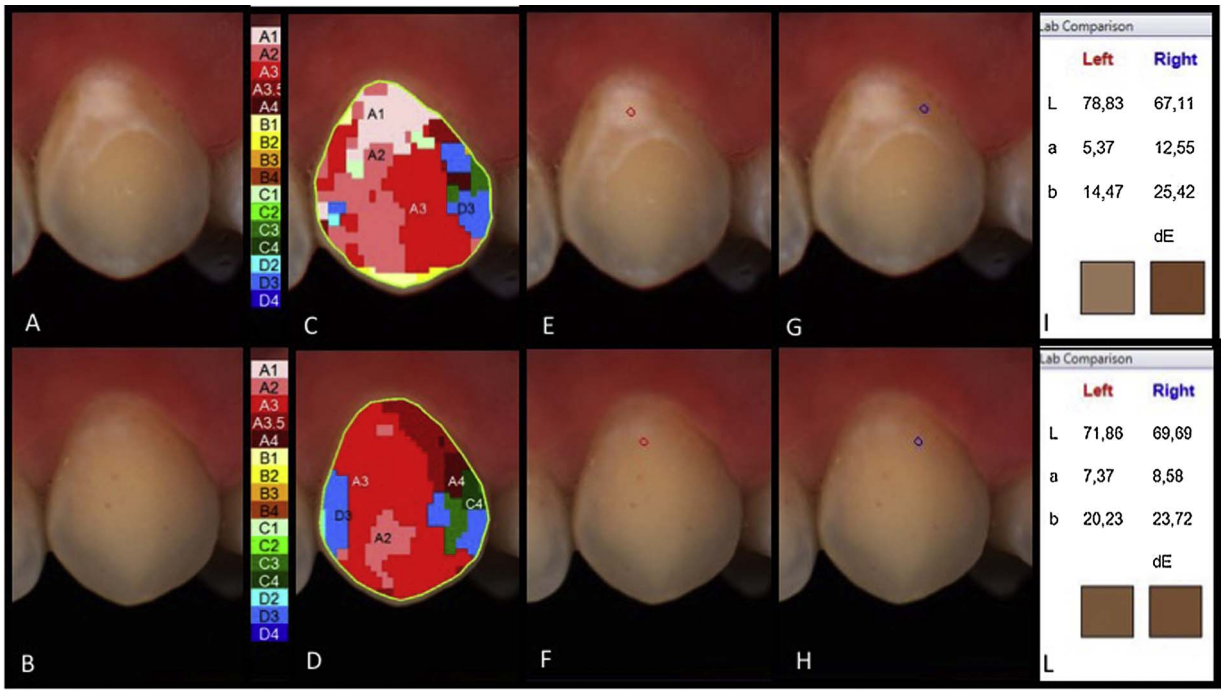

Fig. 1. Example of case record clinical spectrophotometric documentation: (a–b) before and after SP overall clinical crown polarized image; (c–d) before and after colour distribution and overall detailed mapping (Vita 3D Master Scale); (e–h) affected and sound enamel two measurement points before and after resin infiltration; (i–l) CIE L*a*b* colour coordinates of the measurement points.

involves superficial demineralization by application of a 15% solution of hydrochloric acid, which opens up access to the hypomineralized site that can then be infiltrated by a fluid resin. Resin infiltration has been reported to improve aesthetic effect by increasing the refractive index of the lesion, which consequently takes on the appearance of the surrounding sound enamel with restoration of the enamel translucence [7].

A recent *in vitro* study on 30 extracted human teeth compared, for the first time, both quantitative and qualitative tooth-surface aesthetic properties before and after resin infiltrantion [8]. A significant improvement in colour, reverting ECLs colorimetrically altered values back toward the surrounding unaffected enamel, was observed. However, available data on quantitative and qualitative assessment of this newly proposed treatment for hypomineralized enamel lesions in humans are scarce [1–3].

The primary and secondary aims of the present study were to retrospectively evaluate in a cohort of young adolescents: (1) the effect of infiltrative resin treatment on hypomineralized enamel lesions by means of FDI score change before and after treatment; the measurement of the existing colour difference ΔE_{00} between the affected and the sound enamel for each tooth, before and after treatment, by calculating CIEDE2000 colour differences; (2) the correlation between the qualitative FDI-scores and the quantitative ΔE_{00} colour difference.

2. Materials and methods

2.1. Patients

All consecutive patients with hypomineralized enamel lesions on labial surface due to ECLs and/or DDE who, between September 2015 and November 2015, underwent treatment using resin infiltration were retrospectively retrieved from our prospectively maintained institutional database.

Inclusion criteria were ECLs and DDE. Exclusion criteria were MIH.

The study was approved by the local ethical committee and informed consent was obtained from all patients.

2.2. Definition of hypomineralized lesions

Early caries lesions were defined as opaque, matte, chalky white areas, and as having a whitish halo located around the orthodontic brackets.

Developmental defect of enamel was defined as defects of different colours (white/cream and yellow/brown), which can appear as demarcated or diffuse opacities, lines or patchy, diffuse confluent opacities, or a combination of the previous features, or frankly hypoplastic, with symmetrical involvement of groups of homologous teeth [9,10].

2.3. Infiltrative resin treatment procedure

Trained operators performed resin infiltration. Teeth were cleaned, a rubber dam was placed and resin infiltration was performed according to the manufacturer's indications. Treated lesions were etched for 2 min with 15% hydrochloric acid (Icon Etch, DMG) and then rinsed with air-water spray for 30 s. Dessication of the lesions by air blowing for 10 s, followed by application of ethanol (Icon Dry, DMG, Hamburg, Germany) for 30 s, and air blowing again for 10 s was then performed. Application of the infiltrant resin (Icon Infiltrant, DMG) to the lesion under treatment was performed with a sponge applicator provided by the resin infiltration system that was then left in place for 3 min. The excess resin was subsequently removed with air spray and flossed and light-cured for 40 s. The resin infiltration step was repeated a second time with a penetration time of 60 s to allow resin to infiltrate the remaining porosities and light-cured for additional 40 s.

2.4. Qualitative visual evaluation

Visual assessments were made on digital photographs (Nikon D7100, 105 mm Macro lens, R1C1 Macro flash) that were taken before and after the resin infiltration procedure. A representative case is shown in Fig. 1. We used standardized camera settings (shutter speed 1/80 and aperture settings f44). Moreover, the same lighting conditions for capturing all digital photographs were employed. The digital images were viewed on a display that was configured to have a CIE D65

Table 1
FDI values (mean, Std. Err, Std. Dev and 95% Confidence interval) at T_0 and T_1.

Paired *t*-test of all teeth				
FDI score	Teeth	Mean	Std. Err.	95% Conf. Interval
T_0	76	3.71	0.107	3.496 – 3.924
T_1	76	1.64	0.113	1.418 – 1.87
Diff	76	2.06	0.127	1.811 – 2.319
Paired *t*-test of ECL's etiology				
FDI score	Teeth	Mean	Std. Err.	95% Conf. Interval
T_0	43	3.41	0.116	3.183 – 3.653
T_1	43	1.46	0.090	1.283 – 1647
Diff	43	1.95	0.132	1.685 – 2.221
Paired *t*-test for DDE etiology				
FDI score	Teeth	Mean	Std. Err.	95% Conf. Interval
T_0	33	4.09	0.176	3.732–4.449
T_1	33	1.87	0.229	1.411–2.345
Diff	33	2.21	0.237	1.728–2.695

p value: 0.0000 (< 0.05).

(daylight) white point. A formal colour characterization of the imaging setup was not carried out. However, the visual assessments that were made were relative and the before and after images were viewed after being subjected to the same imaging workflow.

Three trained operators with skills in cosmetic dentistry performed the qualitative visual evaluation at T_0 (before treatment) and at T_1 (after treatment) by assessing the change of the FDI-colour match criteria score on before and after treatment images. Qualitative visual evaluation was performed by applying the Fédération Dentaire Internationale (FDI) approved clinical aesthetic colour match and translucency criteria Evaluation scale:

1. Clinically excellent/very good (Good colour match. No difference in shade and translucency);
2. Clinically good (Minor deviations);
3. Clinically sufficient/satisfactory (Clear deviation but acceptable. Does not affect aesthetics);
4. Clinically unsatisfactory (Localised-clinically unsatisfactory, but can be corrected by repair);
5. Clinically poor (Unacceptable. Replacement necessary.) [11].

According to this ranking, five scores were used to qualitatively assess the colour match of the affected and sound enamel per each tooth before and after treatment.

2.5. Quantitative spectrophotometric evaluation and measurements

Quantitative evaluation was performed using a calibrated reflectance spectrophotometer (SpectroShade, MICRO, Serial N HDL1407, MHT, Arbizzano di Negrar, Verona, Italy). Spectrophotometric technical functioning and operative procedures were conducted as described in a previous study [10]. The device was positioned perpendicularly to the labial surface of the clinical crown until a green line appeared on the device's screen to indicate the correct position for obtaining reproducible measurements. Spectral reflectance factors were measured at intervals of 8 nm and the on-board software of the MHT instrument calculated CIE (1976) L*a*b* colour coordinates for specific tooth areas.

Spectrophotometric measurements before and after treatment were performed against a black background (L* = 1.6, a* = 1.2, b* = −1.0) that was positioned behind the tooth. To define the effect of treatment in relation to the extent of the lesion under treatment, two measurement points (sound and affected enamel) were chosen to calculate the colour difference, before and after resin infiltration (see Fig. 1).

The colour change between before and after resin infiltration for each tooth was defined by the CIEDE2000 colour space [12–15], known as ΔE_{00}, which more perceptually uniform that the older CIELAB colour difference.

2.6. Statistical analysis

The R software program (R Foundation for Statistical Computing, Vienna, Austria, ver. 3.2.2) was used for the statistical analyses. A paired *t*-test was used to compare the means of FDI scores and ΔE_{00} values, testing the null hypothesis that the average of the differences between the series of paired observation is zero.

The correlation between visual and spectrophotometric measurements was investigated by using the Pearson correlation coefficient statistic as a measure of the linear correlation between two variables. It ranges from −1 to +1, where 1 indicates a perfect linear correlation and 0 indicates no linear correlation.

3. Results

3.1. Study population

During the study period, 15 patients (mean age 14, range 12–17) who presented with hypomineralized enamel lesions on the labial surface due to ECLs and/or DDE and who were treated using resin infiltration were retrieved from the institutional database. A total of 76 permanent teeth from the 15 patients were treated, with a mean of 5 teeth treated per patient (range 2–10). Therefore, a total of 152 (76 teeth × 2) FDI scores and 152 ΔE_{00} were evaluated, accounting for before and after treatment assessments of the affected and sound measurement points of each tooth.

3.2. Qualitative visual evaluation

FDI-colour match criteria scores are described in Table 1. In the whole sample, the mean FDI score at T_0 was 3,71 and at T_1 was 1,64. The mean difference resulted higher among the teeth presenting with a DDE etiology, however all the observations showed a p value < 0,05.

The distribution of the pre- and post-treatment FDI scores among the whole sample is described in Table 2. Overall, 88.3% of post treatment qualitative visual evaluations were classified as Clinically excellent or Clinically good, and 6.3% as Clinically unsatisfactory or Clinically poor. On the contrary, the pre-treatment evaluation were classified as Clinically unsatisfactory or poor in the 66.4% of the sample and Clinically excellent or good in the 13.2%.

3.3. Spectrophotometric evaluations

The average ΔE_{00} values at T_0 in the whole sample, in the ECL's etiology group, and in the DDE etiology group were 7.15, 6.28, 8,27, respectively (Table 3). After treatment, a decrease was shown in the

Table 2
Distribution of pre-treatment and post-treatment FDI scores.

FDI score	T_0	T_1
1	–	57.9%
2	13.2%	30.4%
3	22.4%	5.4%
4	44.7%	2.7%
5	19.7%	3.6%

Table 3
ΔE_{00} values (mean, Std. Err, Std. Dev and 95% Confidence interval) at T_0 and T_1.

Paired *t*-test of all teeth				
ΔE_{00}	Teeth	Mean	Std. Err.	95% Conf. Interval
T_0	76	7.15	0.447	6.257–8.042
T_1	76	1.73	0.259	1.216–2.251
Diff	76	5.41	0.415	4.588–6.243
Paired *t*-test of teeth presenting with ECL's etiology				
ΔE_{00}	Teeth	Mean	Std. Err.	95% Conf. Interval
T_0	43	6.28	0.531	5.212–7.358
T_1	43	1.01	0.101	0.807–1.218
Diff	43	5.27	0.531	4.199–6.344
Paired *t*-test of teeth presenting with DDE etiology				
ΔE_{00}	Teeth	Mean	Std. Err.	95% Conf. Interval
T_0	33	8.27	0.727	6.795–9.757
T_1	33	2.67	0.546	1.561–3.786
Diff	33	5.60	0.668	4.242–6.963

p value: 0.0000 (< 0.05).

whole sample as in the two groups. The mean difference resulted of 5.41 for the whole sample and of 5.27 and 5.6 in the ECL and DDE groups, respectively. The p value was lower than 0.05 for all the measurements.

3.4. Comparison between visual and spectrophotometric evaluations

We consider whether there is a relationship between the visual assessments (FDI at T_0 and at T_1) and the instrumental assessments (ΔE_{00} at T_0 and at T_1 T). Table 4 shows the Pearson correlation coefficient results.

FDI at T_1 and ΔE_{00} at T_1 show the highest correlation coefficient (0.8188). Statistical analysis showed a significant (p-value < 0.005, Table 4) agreement between FDI scores and spectrophotometric CIEDE2000 measurements.

4. Discussion

We evaluated the subjective and objective outcomes of resin infiltration on hypomineralized enamel lesions due to ECLs and/or DDE, detected on 76 permanent teeth in 15 young adolescents. Our results showed that after resin infiltration the mean colour difference ΔE measured by a reflectance spectrophotometer was always greater than 7.15, which indicated a major restorative and aesthetic effect of resin infiltration on these types of hypomineralized enamel lesions. The aesthetic outcomes were also assessed visually by trained observers and the mean FDI score after treatment was about 1.64, corresponding to being clincially satisfactory or better.

Icon®, first developed to halt caries in the posterior segment, has been recently proposed as a possible alternative to fluoride or caseine phosphopeptide treatments [7]. Not only can resin infiltration restore the hypomineralized site after its exposure by superficial demineralization obtained by application of a 15% solution of hydrochloric acid, but also has a relevant aesthetic effect by increasing the refractive index of the lesion. The final result is that the repaired lesion takes on the appearance of the surrounding sound enamel, with restoration of the enamel translucence [7].

This significant effect in colour, with reversion of the ECLs colorimetric altered values back toward the surrounding sound enamel, has been recently reported in an in vitro study on 30 extracted human teeth [8]. In our study, comparison of both qualitative and quantitative tooth surface aesthetic properties before and after resin infiltration was performed, with *in vivo* spectrophotometric quantitative assessment done for the first time by using the CIEDE2000 colour difference equation. A significant improvement in colour, reverting ECLs colorimetric altered values back toward the surrounding sound enamel, was observed. Prior to this study, available data on quantitative and qualitative assessment of this newly proposed treatment for hypomineralized enamel lesions in humans are scanty.

The qualitative visual evaluation of the tooth before treatment was classified as being Clinically unsatisfactory (FDI mean value 3.71). In the large majority of cases (88.3%) treatment was visually evaluated as Clinically excellent or Clinically good indicating that the colour difference was not only relevant but also aesthetically pleasant. On the other hand, in only 6.3% of cases the aesthetic outcome was evaluated as being Clinically unsatisfactory or Clinically poor. FDI score 5 was observed only in the DDE etiology group, which may indicate something about the efficiency and clinical indications of the resin treatment on the lesions presenting with this etiology, in agreement with previous observations by Paris [6].

The objective evaluation was performed using a calibrated reflectance spectrophotometer [13] and quantified before and after treatment by the CIEDE2000 colour difference equation. Although the mean ΔE_{00} after treatment was of 1.73 in the whole sample, ΔE_{00} was found to be very low (1.01) in the ECL's group and this may represent the clinical efficacy of resin infiltration on lesions within this etiology.

It was shown that the FDI scores that correspond to outcomes that were visually assessed as being clinically excellent, clinically good, clinically satisfactory, clinically unsatisfactory and clinically poor were statistically different. In other words, there was a strong correspondence between subjective (visual) and objective (instrumental) assessments. A more detailed comparison of FDI with ΔE_{00}, at T_1, showed a 0.8188 correlation coefficient. Agreement was greatest for the post treatment evaluations. We believe the agreement was greatest for the T_1, because 93.43% of the evaluated teeth were ranked as FDI 1–2 or 3 score. Moreover, a lower correlation coefficient of 0.6605 was found at T_0, with a mean FDI score of 3.71 and a mean ΔE_{00} of 7.15.

This suggests that instrumental assessment can be used to assess clinical outcomes and that a ΔE_{00} threshold of 1.73 can be used to determine whether the outcome is clinically excellent or good.

It should also be noted that the visual assessments in this work were based on the observation of three observers. However, these observers were highly trained experts who are able to make very reliable judgements. A substantial inter-observer agreement (k = 0.74) was observed. Nevertheless, a greater agreement between visual and instrumental results may be possible if the visual assessments were made by a greater number of observers and averaged over them. Similarly, although the colour-imaging workflow was calibrated it was not characterized. The camera and display settings were fixed so that the images that were viewed were consistently captured and processed. However, a more rigorous colour characterization of the imaging workflow [16] may have produced better results (this would be more important if observers were asked to make an absolute assessment of tooth colour, but in this case observers were asked to compare two images at the same time and make a relative judgment). It is also possible that the

Table 4
Pearson correlation coefficient.

	ΔE_{00}-T_0	ΔE_{00}-T_1	FDI-T_0	FDI-T_1
ΔE_{00}-T_0	1			
ΔE_{00}-T_1	0.4106	1		
	0.0002			
FDI-T_0	0.6605	0.3596	1	
	0	0.0014		
FDI-T_1	0.2342	0.8188	0.3340	1
	0.0417	0	0.0032	

camera was metameric to the CIE standard observer for example.

In conclusion, our results showed that resin infiltration has a strong positive aesthetic effect on hypomineralized enamel lesions due to ECLs and/or DDE in young adults. This effect can be properly recognized by visual evaluations in most cases and a good correlation between visual (subjective) and spectrophotometric (objective) evaluation was observed. Spectrophotometric technology could therefore be consistently used to substantiate visual colour assessment in clinical cosmetic dentistry procedures and to provide quantitative objective records for clinical and forensic purposes. Further investigations are necessary to explore the resin efficiency when taking into account developmental defects of enamel, in order to provide a strong clinical recommendation.

References

[1] M. Denis, A. Atlan, E. Vennant, G. Tirlet, J. Attal, White defects on enamel: diagnosis and anatomopathology: two essential factors for proper treatment (part I), Int. Orthodontics 11 (2013) 139–165.

[2] L. Gorelick, A. Geiger, A. Gwinnett, Incidence of white spot formation after bonding and banding, Am. J. Orthod. 81 (2) (1982) 93–98.

[3] S. Mastroberardino, G. Campus, L. Strohmenger, A. Villa, M. Cagetti, An innovative approach to treat incisors hypomineralization (MIH): a combined use of casein phosphopeptide-amorphous calcium phosphate and hydrogen peroxide–a case report, Case Rep. Dent. 37959 (2012) 3, http://dx.doi.org/10.1155/2012/379593.

[4] Reynolds, Remineralization of enamel subsurface lesions by casein phosphopeptide-stabilized calcium phosphate solutions, J. Dent. Res. 76 (1997) 1587–1595.

[5] M. Sonesson, F. Bergstrand, S. Gizani, S. Twetman, Management of post-orthodontic white spot lesions: an updated systematic review, Eur. J. Orthodontics 39 (2) (2016) (cjw023).

[6] S. Paris, H. Meyer-Lueckle, Masking of labial enamel white spot lesions by resin infiltration-A clinical report, Quintessence Int. 40 (2009) 713–718.

[7] S. Paris, F. Schwendicke, J. Keltsch, C. Dorfer, H. Meyer-Lueckel, Masking of white spot lesions by resin infiltration in vitro, J. Dent. 41 (Suppl. 5) (2013) e28–e34.

[8] K. Hallgren, S. Akyalcin, Color properties of demineralized enamel surfaces treated with a resin infiltration system, J. Esthetic Restor. Dent. 28 (5) (2016) 339–346.

[9] J. Clarkson, D. O'Mullane, A modified DDE Index for use in epidemiological studies of enamel defects, J. Dent. Res. 68 (1989) 445–450.

[10] F. Guerra, M. Mazur, D. Corridore, D. Pasqualotto, G. Nardi, L. Ottolenghi, Evaluation of the esthetic properties of developmental defects of enamel: a spectrophotometric clinical study, Sci. World J. 2015 (2015), http://dx.doi.org/10.1155/2015/878235.

[11] R. Hickel, A. Peschke, M. Tyas, I. Mjör, S. Bayne, M. Peters, R. Hiller Kam Randall, G. Vanherle, S.D. Heintze, FDI World Dental Federation: clinical criteria for the evaluation of direct and indirect restorations-update and clinical examples, Clin. Oral Investig. 14 (4) (2010) 349–366.

[12] Commission Internationale de l'Eclairage (CIE or International Commission on Illumination), CIE Technical Report: Colorimetry, CIE publication, Vienna, Austria, 2004 (no.15.3).

[13] W. Johnston, Color measurement in dentistry, J. Dent. 37 (2009) e2–e6.

[14] F.J. Clarke, R. McDonald, B. Rigg, Modification to the JPC79 colour–difference formula, J. Soc. Dyers Colour. 100 (4) (1984) (128–132.13.).

[15] M.R. Luo, G. Cui, B. Rigg, The development of the CIE 2000 colour-difference formula: CIEDE2000, Color Res. Appl. 26 (5) (2001) 340–350.

[16] M.N. Carney, W.F. Johnston, A novel regression model from RGB image data to spectroradiometric correlates optimized for tooth colored shades, J. Dent. 15 (2016) 45–48.