Influence of enamel composite thickness on value, chroma and translucency of a high and a non-high refractive index resin composite

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Abstract

Objectives: To evaluate the influence of thickness on the optical properties of two enamel shade composites, one with a high refractive index and one traditional.
Methods: A medium value enamel shade was selected from the resin composites Enamel Plus HRi (UE2) and Enamel Plus HFO (GE2). Enamel Plus HRi is a high refractive index composite. Samples were fabricated in five different thicknesses: 0.3, 0.5, 1, 1.5 and 2 mm. Three specimens per material and thickness were fabricated. Three measurements per sample, over white, black and dentin composite background were generated with a spectrophotometer (Spectroshade Micro, MHT). Value, chroma, translucency and color differences (ΔE) of the specimens were calculated. Results were analyzed by the Pearson correlation test, ANOVA and a post-hoc Tukey test.
Results: Increasing the thickness of the enamel layers decreased the translucency and the chroma of the substrate for both materials tested. For HRi the increase of the thickness resulted in an increase of the value, whereas for HFO it resulted in a reduction of the value. The two composites showed a significant difference in value for each thickness, but not in translucency and chroma. Color difference between them was perceptible in layers equal or higher than 0.5 mm.
Conclusions: The high refractive index enamel (HRi) composite exhibits different optical behavior compared to the traditional one (HFO). HRi enamel composite behaves more like natural enamel as by increasing the thickness of the enamel layer, the value also increases.
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Introduction

Replicating tooth form, color, translucency and surface texture is the ultimate goal of every esthetic restoration, either direct or indirect. In order to create life-like, "invisible" restorations, the optical properties of both natural teeth and the restorative materials should be thoroughly understood.

Color is determined by three dimensions according to the Munsell Color Order System: hue, chroma and value (lightness).[1] Hue is the quality by which one color family is distinguished from another ie, red from blue, green from yellow. Chroma is the intensity or the saturation of the hue, and it expresses how close the color is to either gray or the pure hue. Value is defined as the quantity of light an object reflects when compared to a pure white diffuser (100% reflection) and a black absorber (0% reflection).

In addition to value, hue and chroma, other, secondary optical properties of the tooth exist and can strongly affect the overall appearance of the tooth. These include translucency, opalescence and fluorescence.

Translucency is the ability of a layer of a substance to allow the appearance of an underlying background to show through.[2]

Opalescence is an optical property, where there is light scattering of the shorter wavelengths of the visible spectrum, giving the material a bluish appearance under reflected light and an orange/brown appearance under transmitted light.[3] This light scattering is caused by particles smaller than the wavelength of visible light that are dispersed in a translucent material of a much lower refractive index.[4] In restorative dentistry, opalescent dental ceramics already include the presence of microparticles or phase-separated glass particles to scatter incident light, which allow the clinician to manage esthetic problems, and also to simulate the natural translucency and brightness of teeth.[5,6]

Fluorescence is the absorption of light by a substance and its emission at the same time at a usually longer wavelength. Such a substance emits more visible light than it receives.[7] Vanini and Mangani described how to understand and reproduce the color dimensions in clinical restorative work.[8]

Tooth color is the result of the interaction of enamel, dentin and pulp with light. These tissues have different structural characteristics and, consequently, they exhibit different light wave characteristics. The optical properties and the thickness of these tissues determine the final tooth color.

Tooth color is predominately determined from dentin, and enamel contributes in tooth color in the form of scattering at wavelengths in the blue range.[9] Enamel has a highly mineralized prismatic structure, low organic content and a small amount of water. It exhibits a higher transmission of light than dentin[10] and is usually achromatic, even though it sometimes tends to have a yellowish-white or greyish-white aspect.[11] Dentin has less mineral content, a higher water content and an organic tubular structure. It is less translucent than enamel and its saturation (chroma) increases over the years.[11]

The translucency of enamel and dentin tend to vary because of the thickness of the tissue. The thicker the tissue, the less translucent it appears. In natural teeth enamel, thickness varies greatly: it is higher at the incisal third and decreases towards the cervical third. Therefore, translucency is higher at the cervical part of the tooth, allowing more of the underlining dentin to show through. Similarly, in young patients, where enamel is thicker, teeth seem more opaque and of higher value.[11-13]

Since natural tooth color derives from the combination of the optical properties of enamel and dentin, it seems reasonable to try to imitate this layered structure using two optically different restorative materials. For this purpose, resin composites have been developed that exhibit optical properties similar, but in reality are not identical[14-16] to the tissues they intend to restore. Generally, composite resins used for dentin restoration are less translucent and highly chromatic, compared to the composites for enamel that are highly translucent and less chromatic. By utilizing an anatomic stratification with successive layers of dentin and enamel composites, a more realistic depth of color can be achieved. However, since the optical properties of composite resins designed for stratification technique are not identical to the optical properties of the tooth tissues,[14-16] it is not always advisable to place the enamel layer in the same thickness as the natural enamel.[17]

Another characteristic of materials is their refractive index. The refractive index of an optical medium describes how light, or any other radiation, propagates through that medium. It is defined as the ratio between the speed of light in vacuum and the speed of light in the optical medium and is a characteristic property, typically used to determine materials.[18,19] Hard dental tissues and restorative materials usually present different refractive indices. Consequently, if composite is placed in the same thickness as natural enamel, optical integration will not be successful.

The thickness of the different composite layers plays an important role in the final outcome. Layer thickness and the proportion of thicknesses of the dentin and translucent shade greatly influence the final aspect of a multilayer composite restoration.[20] If a thick layer of enamel shade is placed over a dentin shade, the sample will appear to be darker, ie, the value will be decreased.[21,22] Similarly, in another study, increasing the thickness of the enamel composite layer was responsible for a decrease in the value and an increase in the chroma.[23] Moreover, the translucency of composite resins is influenced by the thickness. More specifically, increasing the thickness of the composite decreases its translucency.[24,25]

The great variability of materials on the market and the numerous color characteristics of these materials can provide the clinician with the potential to achieve an esthetic result and excellent imitation of nature. On the other hand, this variety can be confusing as there are no guidelines for the expected outcome and this does not allow the dentist to get predictable color results.

A nanohybrid resin composite (Enamel Plus HRi, Micerium) has been developed by Lorenzo Vanini, which claims to have a refractive index identical to that of natural enamel (1.62). It is suggested to use this material in the same thickness

Table 1 The materials used in the study

Brand	Manufacturer	Shades	Type	Composition
Enamel Plus HFO	Micerium	GE2 Enamel	Microhybrid	53% vol 75% weight
Enamel Plus HRi	Micerium	UE2 Enamel	Nanohybrid	63% vol 80% weight
Enamel Plus HRi	Micerium	UD3 Dentin	Microhybrid	53% vol 75% weight

as the natural enamel, without lowering the value of the restoration.

This high refractive index composite has not been much investigated in the literature, as well as the possible differences with the previous microhybrid composite (Enamel Plus HFO, Micerium).

The present study aims to investigate the possible differences compared with the previous microhybrid composite and whether this high refractive index composite is able to behave in a similar manner to natural enamel. The purposes of the present study are:

- To investigate the differences in value, chroma and translucency of the enamel shade resin composites intra and intergroups (HRi and HFO) in various thickness, and their influence on the dentin shade composite substrate.
- To examine whether the color differences of the two enamel shade resin composites in different thickness are clinically perceptible.

The null hypotheses were threefold:

- Different thicknesses do not affect the chroma, the value or the translucency of enamel-shade composite resins.
- There are no differences in chroma, value and translucency among different composite resins.
- Different thicknesses do not affect the color difference of the two enamel shade resin composites.

Materials and methods

Two resin composites were selected for the study: Enamel Plus HRi (Micerium) and Enamel Plus HFO (Micerium). Each composite system has three different value shades for the restoration of the enamel: high, medium and low. According to the company, the Enamel plus HRi system has a higher refractive index, similar to natural enamel. In the present study, only the medium value enamels were compared at five different thicknesses: GE2 (Enamel Plus HFO) and UE2 (Enamel Plus HRi) (Table 1).

Specimen preparation

The specimens were fabricated using a stainless steel matrix designed to produce porcelain disks (Porcelain Sampler, Smile line). The matrix had a 12 mm circular platform that could be retracted, enabling the fabrication of specimens of different thicknesses. After application of the composite paste into the matrix, a glass slide was pressed with a 100 gr steel block for 60 s to achieve a uniform thickness of the disk specimens. All samples were light cured for 60 s with an LED curing light (Freelight S10, 3M Espe) and with a constant output of 1,200 mW/cm^2. Enamel composite samples were fabricated at four different thicknesses: 0.3 mm, 0.5 mm, 1 mm, 1.5 mm and 2 mm (Fig 1). Three specimens were fabricated per thickness and per enamel shade, in a total of 30 specimens.

The manufacturer recommends using the proper dentin (HRi and HFO) with the HRi and HFO enamels respectively. HRi and HFO dentin samples, 3 mm thick, of UD3 shade (equivalent to A3) were fabricated and their color coordinates were measured with a spectrophotometer. Since no significant differences were detected and in order to eliminate an additional variable, in the present study, the same dentin background has been used with all the enamel samples: UD3 HRi (Fig 2).

A series of color measurements were performed using a spectrophotometer (Spectroshade Micro, MHT) (Fig 3). Color measurements were made according to the CIELab color system. There are three color parameters: "L," which refers to lightness, is an achromatic coordinate, and is ranging from black (0) to white (100); "a," which is a chromatic coordinate representing the green-red axis (negative values indicate green and positive values indicate red) and "b," which is also a chromatic coor-

Fig 1 Samples of enamel composite (HRi and HFO) with various thickness (0.3, 0.5, 1.0, 1.5, and 2.0 mm).

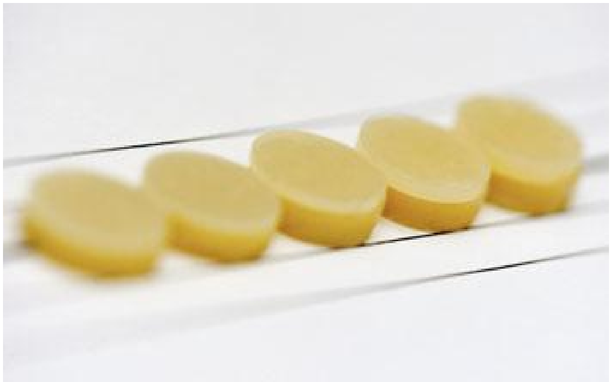


Fig 2 Samples of dentin UD3 (3 mm thickness) with enamel samples of different thickness on the top.

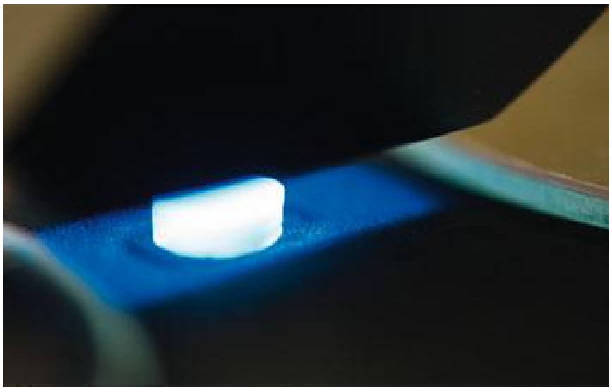


Fig 3 Spectrophotometer in action generating the color data of an enamel sample over a dentin base of 3 mm on a dark background. Photo was taken without the jig in place.

dinate referring to the blue-yellow axis (negative values indicate blue and positive values indicate yellow).

All measurements were performed over three different backgrounds: white, black and the 3 mm dentin sample (placed over a black background). Three consecutive measurements were generated per specimen. Consequently, nine measurements were accomplished per enamel specimen per each background. The total number of measurements was 270. For each specimen, the average value of L, a, and b color coordinates over each background were calculated.

Between the specimen and each background, an optical fluid was placed to achieve optical contact. This can guard against errors that might be caused by a variable air interface. To ensure the correct positioning of the spectrophotometer aperture over the sample surface a special jig was used. Calibration of the spectrophotometer was performed using special white and green tiles that were provided by the manufacturer and according to the manufacturer's instructions.

The translucency parameter was calculated with the equation:

$$TP = [(L_b - L_w)^2 + (a_b - a_w)^2 + (b_b - b_w)^2]^{1/2}$$

where subscript b refers to the color parameters on the black background and subscript w refers to those on the white background.

The value of each enamel-dentin sample is equal to the L color coordinate.

The chroma of each enamel-dentin sample is calculated with the equation: $C = (a^2 + b^2)^{1/2}$

The color difference between the two enamel shade composites (HFO and HRi) at each given thickness was calculated with the equation:

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

Value, chroma and color differences were calculated with the enamel samples over the dentin background.

Data analysis

Descriptive statistics were used to present the specimen population (mean ± SD). To verify the influence of thickness on the optical parameters (value, chroma and translucency), the Pearson correlation coefficient (r) was calculated with linear regression analysis within each tested composite resin ($\alpha = 0.05$). Intergroup analysis was performed using two-way analysis of variance (ANOVA), followed by the use of the Tukey post hoc test ($\alpha = 0.05$). Data analysis was performed using commercially available statistical software (JMP, 5.0.1a, SAS Institute).

Results

The means and standard deviations of the experimental groups for CIE Lab values are described in Table 2. Chroma, value and translucency data are described in Table 3 and graphically presented in Chart 1.

Table 2 Descriptive statistics of CIE Lab values at different thickness with the dentin composite background

Composite resin	Thickness (mm)	L Mean (SD)	a Mean (SD)	b Mean (SD)
UE2 (HRi)	0.3	67.42 (0.55)	1.73 (0.06)	17.96 (0.73)
	0.5	68.72 (1.03)	1.49 (0.14)	17.08 (1.16)
	1.0	68.35 (1.46)	1.51 (0.16)	16.26 (0.26)
	1.5	69.37 (1.22)	0.74 (0.32)	14.32 (1.75)
	2.0	69.16 (1.14)	0.64 (0.19)	14.23 (0.84)
GE2 (HFO)	0.3	66.2 (0.62)	2.20 (0.08)	17.50 (0.29)
	0.5	66.20 (0.84)	1.88 (0.06)	16.72 (0.38)
	1.0	65.35 (0.86)	1.77 (0.08)	15.92 (0.20)
	1.5	65.32 (0.22)	1.63 (0.03)	15.14 (0.10)
	2.0	66.11 (0.46)	1.22 (0.07)	14.63 (0.13)

Table 3 Descriptive statistics of chroma, value and translucency at different thickness; for chroma and value measurements, the dentin background was used

Composite resin	Thickness mm	Chroma Mean (SD)	Value Mean (SD)	Translucency Mean (SD)
UE2 (HRi)	0.3	18.05 (0.73)	67.42 (0.55)	39.59 (3.58)
	0.5	17.15 (1.16)	68.72 (1.03)	30.37 (2.45)
	1.0	16.33 (0.25)	68.35 (1.46)	27.34 (1.11)
	1.5	14.34 (1.76)	69.37 (1.22)	21.15 (1.94)
	2.0	14.25 (0.85)	69.16 (1.14)	18.84 (2.40)
GE2 (HFO)	0.3	17.64 (0.30)	66.2 (0.62)	45.21 (1.44)
	0.5	16.83 (0.39)	66.20 (0.84)	35.23 (3.21)
	1.0	16.02 (0.21)	65.35 (0.86)	27.57 (0.59)
	1.5	15.23 (0.10)	65.32 (0.22)	21.54 (1.56)
	2.0	14.68 (0.13)	66.11 (0.46)	19.04 (1.16)

Chart 1 Mean chroma, value and translucency at different thickness of enamel layer (descriptic analysis); for chroma and value measurements, the dentin background was used

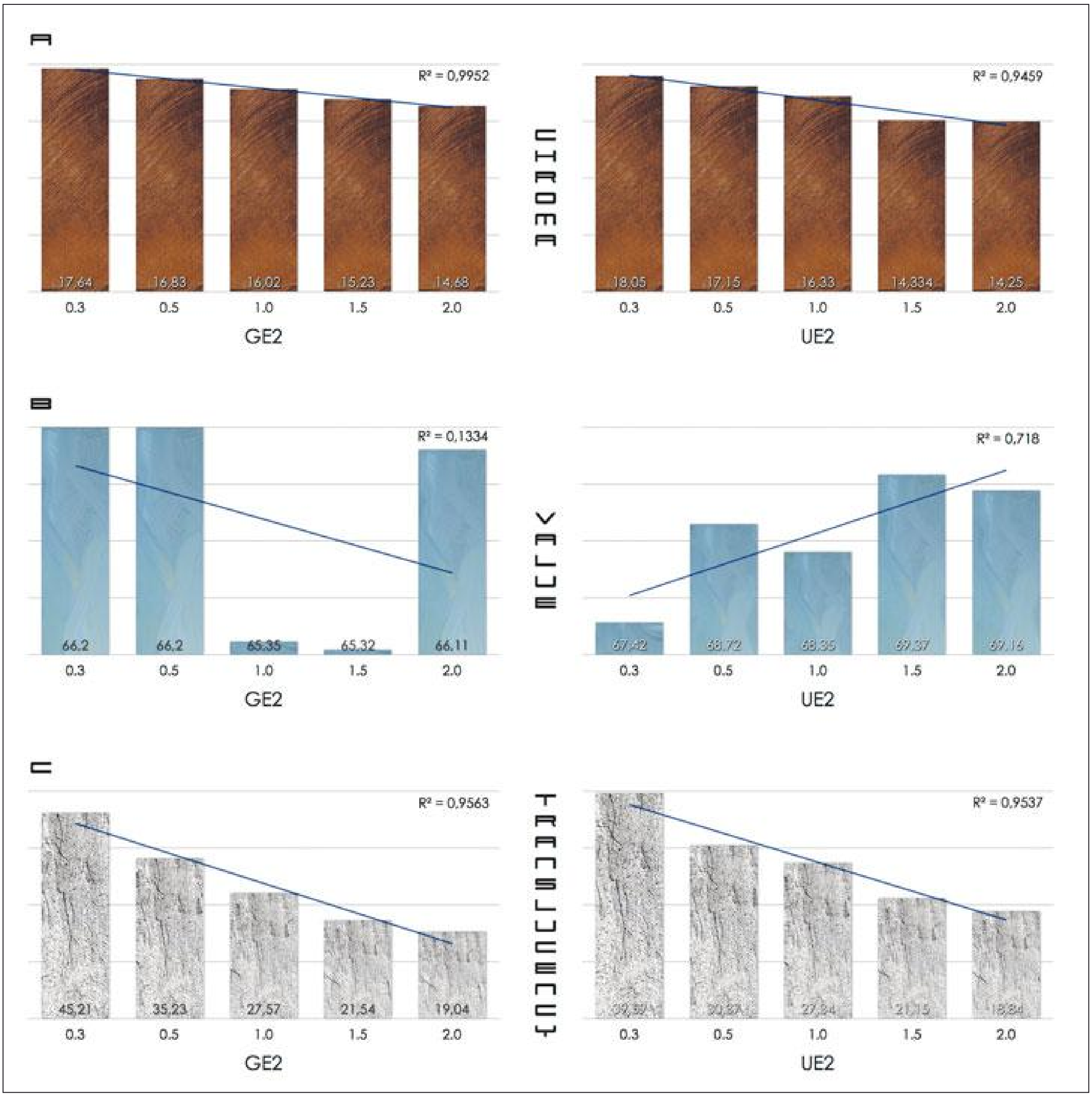


Chart 2 Linear regression analysis results (intragroups analysis; Pearson correlation coefficient; $\alpha = 0.05$)

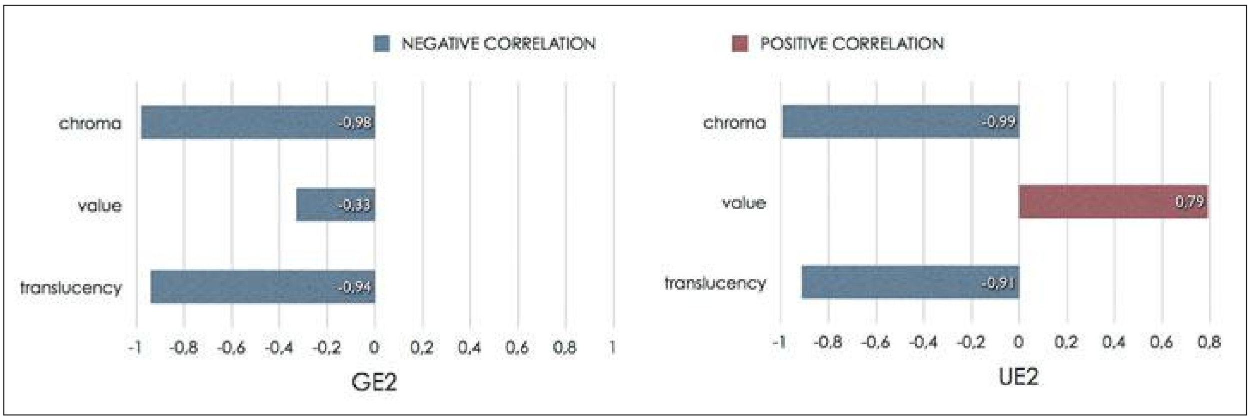
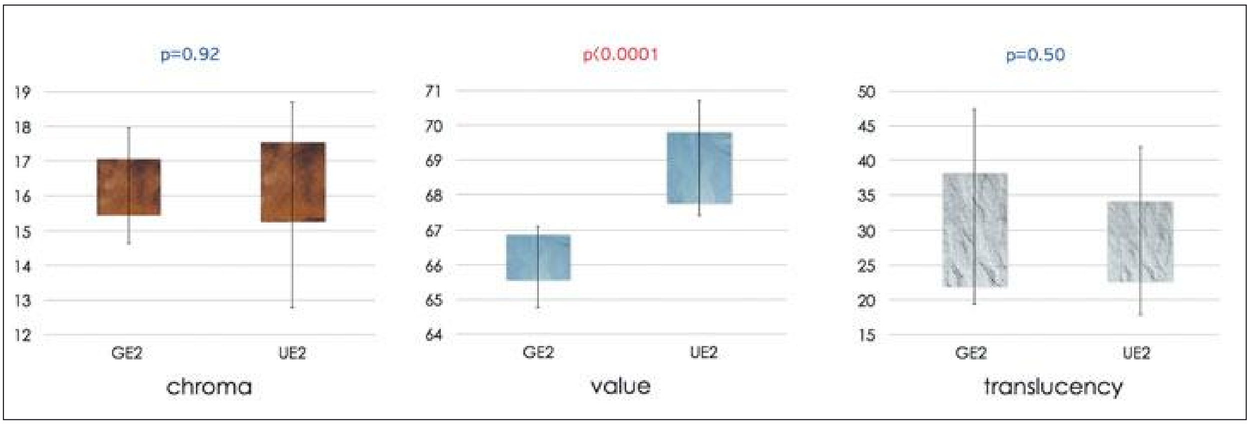


Chart 3 Two-way ANOVA results in terms of chroma, value and translucency (inter-groups analysis; $\alpha = 0.05$)



Intragroup analysis

Pearson correlation coefficients showed a strong and negative correlation between thickness and all chromatic parameters tested for the GE2 (HFO) group (Chart 1). Increasing the thickness of the enamel layers decreased the chroma ($r = -0.98$), the value ($r = -0.33$) and the translucency ($r = -0.94$) of the specimens.

Regarding the UE2 (HRi) group, changing the enamel layers' thickness resulted in a significant decrease in chroma ($r = -0.99$) and translucency ($r = -0.91$) of the final restoration. On the contrary, the value was strongly and positively correlated with the increase of the enamel layers ($r = 0.79$) (Chart 2).

Intergroup analysis

Despite the thickness of the enamel layers, the intergroup analysis showed a statistically significant difference in terms of value (brightness) between the UE2 (HRi) and GE2 (HFO) composite

Chart 4 Two-way ANOVA results in terms of chroma, value and translucency at different thickness (intergroups analysis; α = 0.05)

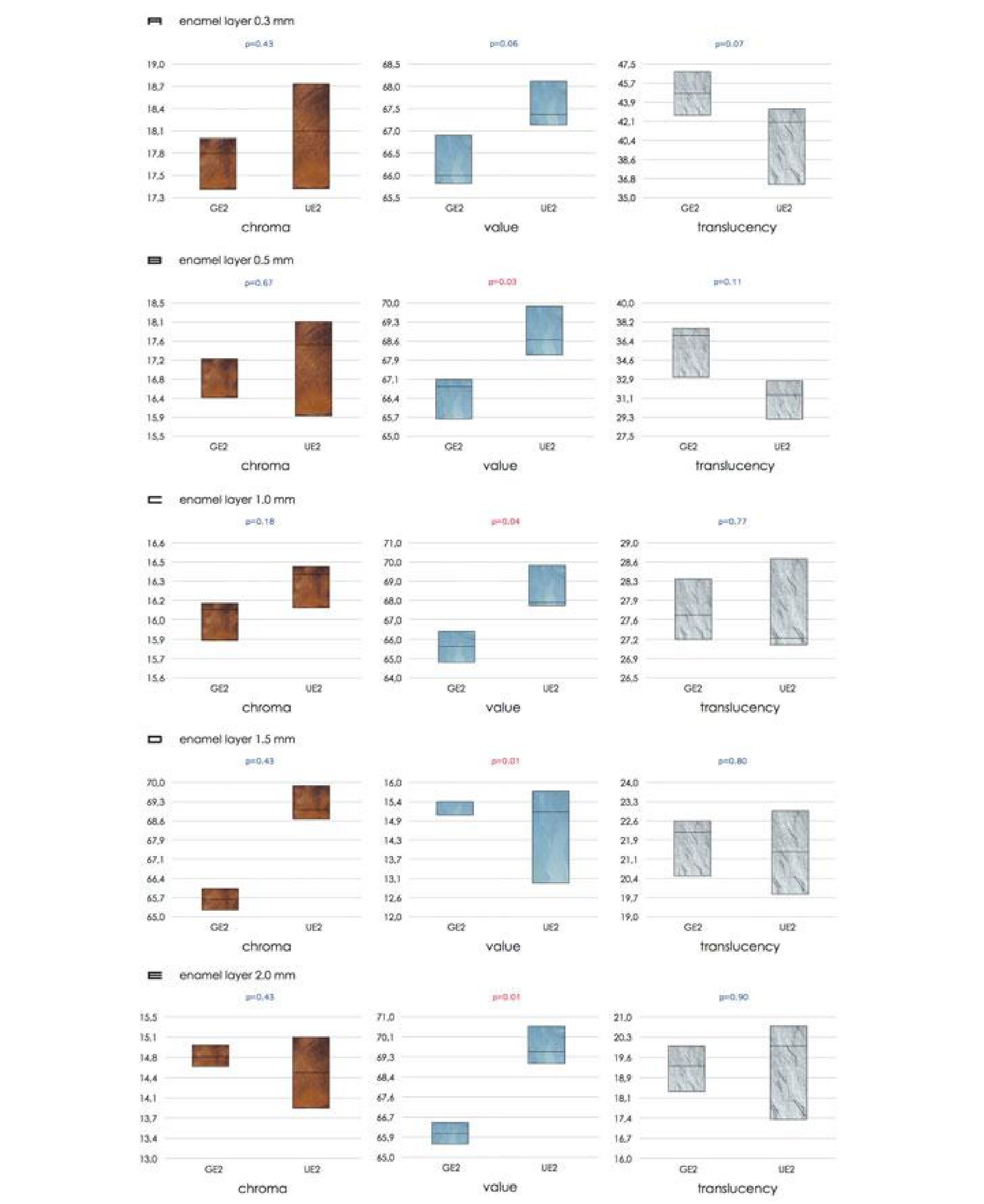


Table 4 Two-way ANOVA for inter-group analysis at different thickness

Thickness mm	Chroma F Ratio (P)	Value F Ratio (P)	Translucency F Ratio (P)
0.3	0.78 (0.43)	6.46 (0.06)	6.36 (0.07)
0.5	0.21 (0.67)	10.82 (0.03)	4.35 (0.11)
1.0	2.71 (0.18)	9.36 (0.04)	0.10 (0.77)
1.5	0.76 (0.43)	32.39 (0.01)	0.07 (0.80)
2.0	0.76 (0.43)	18.55 (0.01)	0.02 (0.90)

Table 5 CIELab color parameters differences and color difference between UE2 (HRi) and GE2 (HFO) groups at different thickness

Thickness mm	ΔL	Δa	Δb	ΔE
0.3	-1.22	0.47	-0.46	1.39
0.5	-2.52	0.39	-0.36	2.58
1.0	-3.00	0.26	-0.34	3.03
1.5	-4.05	0.89	0.82	4.23
2.0	-3.05	0.58	0.40	3.13

resins (F = 60.97, *P* < 0.0001). No differences were detected in chroma (F = 0.01, *P* = 0.92) and translucency (F = 0.47, *P* = 0.50) for the tested materials (Chart 3).

Results regarding the chromatic differences between the two experimental groups relating to thickness of the enamel layers are reported in Table 4. No significant differences were found between the UE2 (HRi) and GE2 (HFO) specimens in terms of chroma and translucency at different thicknesses of the enamel layers (Chart 4, A–E). Data regarding the value showed a higher brightness for the specimens of the UE2 (HRi) group, at a thickness of the enamel layer equal or thicker than 0.5 mm (Chart 4, B–E). No statistically significant differences were found between the two experimental groups in terms of value at a thickness of the enamel layer equal to 0.3 mm (F = 6.46, *P* = 0.06) (Chart 4, A).

ΔE evaluation

The color differences between the two experimental groups are reported in Table 5. Setting ΔE = 1.8 as the perceptibility threshold value,[26] chromatic

Fig 4 Appearance of enamel samples of different thickness (0.3, 0.5, and 1.0 mm) of HRi (UE2) and HFO (GE2) composites on a UD3 dentin composite base.

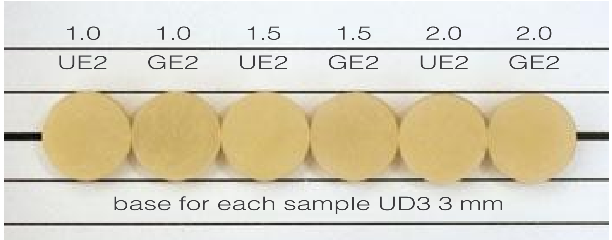


Fig 5 Appearance of enamel samples of different thickness (1.0, 1.5 and 2.0 mm) of HRi (UE2) and HFO (GE2) composites on a UD3 dentin composite base.

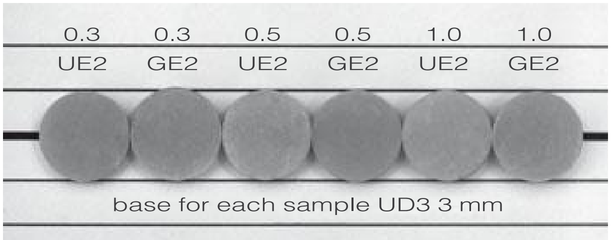


Fig 6 Appearance in black and white of enamel samples of different thickness (0.3, 0.5, and 1.0 mm) of HRi (UE2) and HFO (GE2) composites on a UD3 dentin composite base. This image is useful to perceive the differences in value.

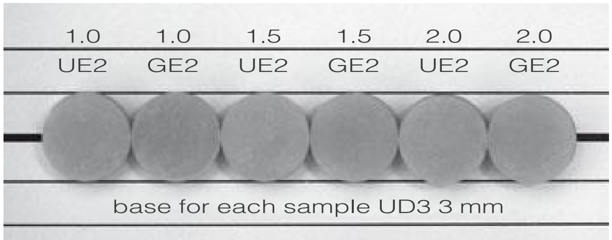


Fig 7 Appearance in black and white of enamel samples of different thickness (1.0, 1.5, and 2.0 mm) of HRi (UE2) and HFO (GE2) composites on a UD3 dentin composite base. This image is useful to perceive differences in value.

differences between the UE2 and GE2 specimens were visually detectable in enamel composite layers equal or thicker than 0.5 mm. No chromatic differences were clinically detectable within 0.3 mm of thickness of the enamel layer ($\Delta E = 1.39$).

Discussion

Color has a fundamental role for the clinician who must perform a restoration that integrates with the rest of the dentition. Selecting the composite masses to be used in restorations is one of the issues in which the clinician devotes a lot of energy, and probably neglects to determine the thickness. However, changes in thickness can result in completely different values, chroma, hue, translucency, and opalescence. Therefore, the changes of color of enamel composite in various thicknesses definitely become one of the most important aspects to be analyzed.

The results allow different clinical reflections, pertinently to the aims of the current study (Figs 4 to 10). Increasing the thickness of the enamel layer resulted in a significant decrease of translucency for both materials tested (Fig 10). Arimoto et al and Schmeling et al also report a reduction of translucency as the thickness of the sample increases.[24,25] When the thickness of the specimen was equal or higher than 1 mm, translucency of the two composites was very similar. For thickness 0.3 mm and 0.5 mm GE2 (HFO) exhibited higher translucency, even though not statistically significant. The threshold at which translucency differences are detectable has not been established yet. Consequently, it is not possible to know whether this difference is noticeable or not. However, in clinical practice where enamel composite thickness is usually below 1 mm, the aforementioned difference in translucency could possibly have an impact in the final result.

As for chroma, there is a significant, negative correlation between chroma and thickness for both the GE2 and UE2 composites. Duarte et al reported that chroma increases by increasing the thickness of the enamel shade composite.[23] In their study, no dentin background was used, in contrast to the present study. When there is a dentin background, the increase of enamel layer results in a desaturation of the dentin color.

As far as the value is concerned, the two enamel composites behaved differently. GE2 exhibited a decrease of the value, while UE2 showed exactly the opposite behaviour. Friebel et al 2012 and Schmeling 2009 supported the view that by increasing the thickness of the enamel layer the restoration appears darker (lower value).[21,22] This is in agreement with our findings for the GE2, but not for the UE2 composite.

In natural dentition, increased thickness of enamel increases the value of the teeth. In young patients, where enamel is thicker as it has been less exposed to damage caused by brushing and by acids in the diet, teeth ap-

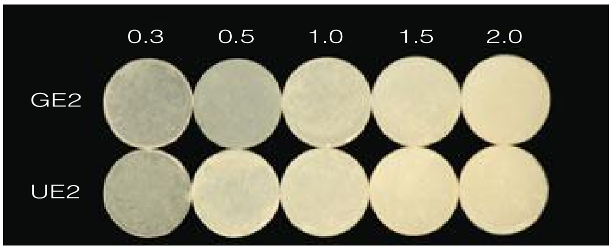


Fig 8 Comparison of enamel samples of different thickness (0.3, 0.5, 1.0, 1.5, and 2.0 mm) of HRi (UE2) and HFO (GE2) composites over a black background.

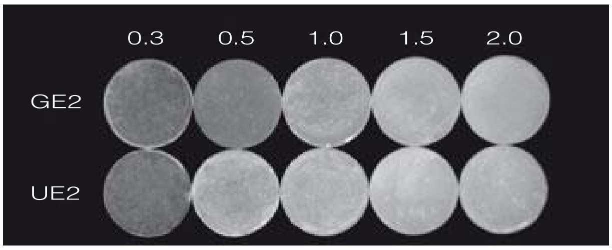


Fig 9 Comparison in black and white of enamel samples of different thickness (0.3, 0.5, 1.0, 1.5 and 2.0 mm) of HRi (UE2) and HFO (GE2) composites over a black background. This image is useful to perceive the differences in value.

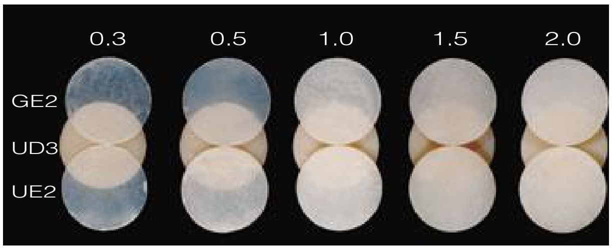


Fig 10 Appearance of enamel samples of different thickness (0.3, 0.5, 1.0, 1.5, and 2.0 mm) of HRi (UE2) and HFO (GE2) composites over a black background and a UD3 dentin composite base. The translucency of each sample and the difference in translucency between the samples is evident.

pear more opaque and of a higher value. The results of the current study suggest that enamel UE2 composite behaves similarly with natural enamel, as the value increases, the thickness increases. However, this is not true for enamel GE2 composite, which has a similar behavior to the majority of the composite materials available on the market. A possible explanation could be the difference in the refractive index, with UE2 having a refractive index equal to natural enamel, as stated by the manufacturer.

The clinical impact of this result in composite layering could be that with the HRi enamel, the clinician can perform real anatomical stratification of composite using the natural thickness of hard tissues as a guide, and not arbitrarily placing thinner layers of enamel composite. On the other hand, the thickness should be carefully evaluated because using enamel layers that are too thick may result in a final restoration that is of very high value.

Results indicate that with the exception of the 0.3 mm thickness, there is a significant difference between the two materials for the value parameter but not for the chroma. Therefore, the null hypothesis has to be partially rejected. That means that by choosing to restore enamel with UE2 composite, the restoration will have a higher value, provided that it is placed in a layer equal or thicker than 0.5 mm, which is the clinical case in most of the times in the middle and incisal third of the crown.

Several studies have attempted to determine perceptibility and acceptability visual thresholds. In 1979, Kuehni and Markus first established a perceptibility threshold of 1 ΔE unit for 50% of observers using textile specimens and matte paints under optimal viewing laboratory conditions.[27] Ruyter et al examined monochromatic resin composite specimens under laboratory conditions and reported that 50% of observers considered the color difference unacceptable when it was approximately 3.3 ΔE units.[28] Instead of using laboratory conditions, Johnston and Kao examined composite veneers and the adjacent or contralateral unrestored teeth under *in vivo* conditions and determined 3.7 ΔE units as the perceptibility threshold and 6.8 ΔE units as the acceptability threshold.[29] Douglas et al replicated an actual clinical scenario using spectroradiometric instrumentation and found that the 50% perceptibility threshold was 2.6 ΔE units and the 50% acceptability threshold was 5.5 ΔE units.[30] In 2010, a study by Ghinea et al sets these thresholds even lower: the 50% perceptibility threshold is 1.80 and the 50% acceptability threshold is 3.46.[26] In the current study, the 1.80 ΔE units threshold was used, in accordance with the study of Ghinea et al. Color difference between the two materials examined is clinically perceptible, in all cases except the 0.3 mm thickness. The null hypothesis has to be rejected. However, in all but the 1.5 mm thickness these color differences remain clinically acceptable.

The clinical goal is to achieve an excellent match of the restoration with the hard dental tissues. For the clinician it is useful to realize that for very low material thickness (0.3 mm) the difference between HRi and HFO (that behaves like the majority of composite already described from literature) is not detectable, but as thickness increases the optical behavior changes and therefore the management of the material should be adequate. It is obvious that there is a graduate increase of the ΔE value with an increase of the sample thickness. This could be possible due to the decrease of translucency that does not permit the dentin background color to show through and so enamel composite plays a more important role.

To better understand the optical behavior of the two enamels, complementary to the present study, a full tooth in composite was fabricated using for the left half part UE2 (HRi) enamel composite and for the right half part GE2 (HFO) composite. A very simplified layering technique was used, with only one dentinal body UD3 (HRi) and no translucent effects and opalescence masses. The thickness of the two different enamels was very similar, considering the anatomical variations between the mesial and distal parts. Some stains were inserted in the body to better perceive the translucency of the two enamels (Figs 11 to 13). Finishing was performed with diamond burs, aluminum oxide discs, polishing pastes in two different grain measures: diamond pastes at 3 μm and 1 μm and finally, aluminum oxide paste at 1 μm (Shiny, Micerium) (Fig 14). The difference in the appearance of the two enamels (HRi and HFO) is perceptible, not in the cervical part where the enamel is very thin (around 0.3 mm) but where enamel is thicker, especially in the middle and incisal thirds.

One more aspect that plays a significant role in the final esthetics of a restoration is the opalescence effect (Figs 15 and 16). It has already been reported

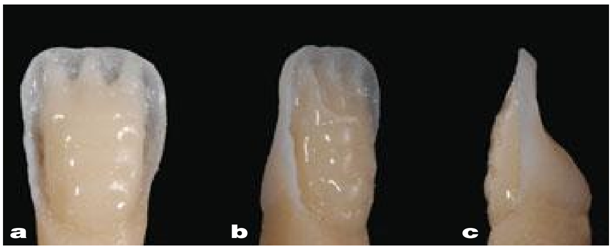


Fig 11 Composite build up tooth layering phases. The left half palatal shell is HRi (UE2) and the right half is HFO (GE2). This layering approach is simplified in order to compare the two enamels and made only with one single dentin (UD3) for the body. Frontal view **(a)** and lateral views **(b and c)** to perceive the thickness.

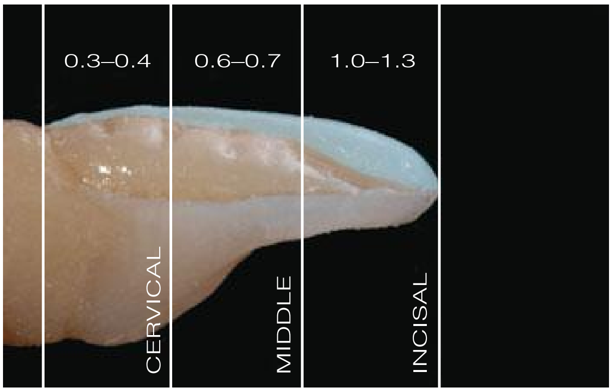


Fig 12 Progressive thickness of enamel layering in mm, from cervical to incisal third. In this case, during the finishing phases the incisal will be slightly reduced to better represent the Kuwata Planes.

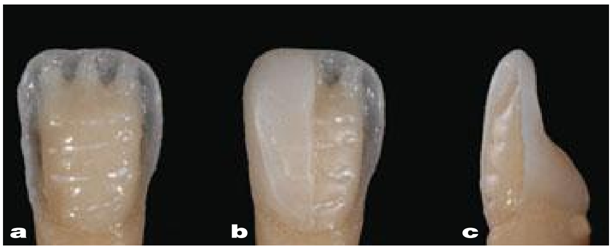


Fig 13 Composite build up tooth layering phases. The buccal left half enamel layer is HRi (UE2) and the right half is HFO (GE2). This layering approach is very simplified: only one dentinal body and no translucent and opalescent masses. Only some stains are inserted in the body to understand the translucency of the two enamels. Frontal view **(a and b)** and lateral view **(c)** to perceive the thickness of the enamel layer.

Fig 14 Composite build up tooth finishing and polishing phases. Finishing was performed with diamond burs, aluminum oxide discs and polishers. Polishing with diamond pastes of grain size 3 µm **(a)** 1 µm **(b)** and aluminum oxide paste 1 µm **(c)**.

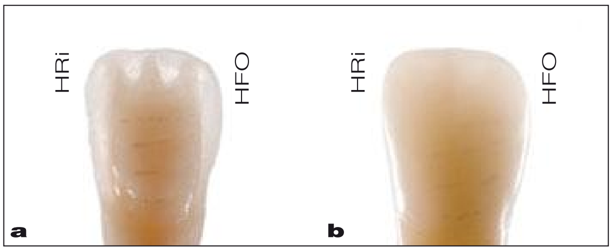


Fig 15 Composite build up tooth observed under transmitted light, without the buccal shell of enamel **(a)** and completed and polished **(b)**. The difference in opalescence between the two enamels (HRi and HFO) is visible.

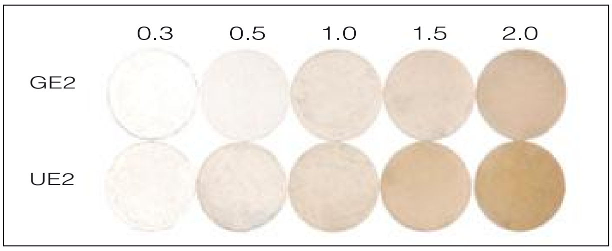


Fig 16 Appearance of enamel samples of different thickness (0.3, 0.5, 1.0, 1.5, and 2.0 mm) of HRi (UE2) and HFO (GE2) composites under transmitted light. The difference in opalescence between the two enamels (HRi and HFO) is visible.

that the refractive index can interfere with the opalescence effect. From Fig 16 it was observed, although not measured, that the samples of the high refractive index enamel UE2 (HRi) could be more prone to emulate the opalescent effect, compared with composite GE2 (HFO), especially in 0.5 mm thickness. This estimation lacks colorimetric data but it could be very interesting for the clinician and should be further investigated. If this estimation is confirmed, it could be possible that it is not mandatory to use yellowish or amber effects to simulate the natural opalescent effect when layering at an incisal restoration.

The different optical behavior is perceivable (Fig 17a) and the black and white version emphasizes the difference in terms of value (Fig 17b). Within the limitation of this single sample, the results of this study are visualized in this full composite layered tooth (Figs 15, 17, and 18).

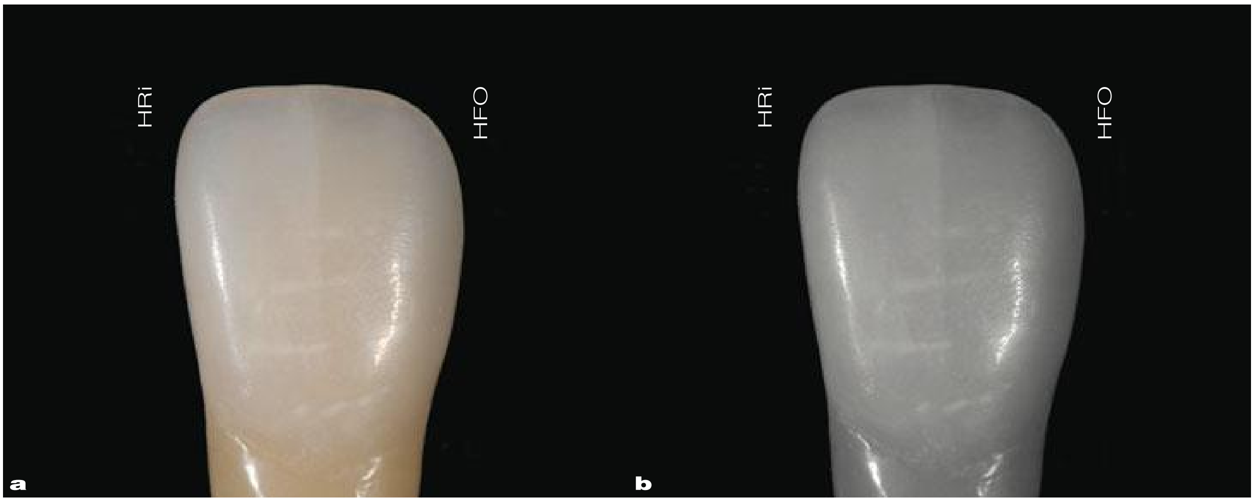


Fig 17 Composite build up tooth completed and polished. Layering was performed with the two enamels in very similar thickness, considering the anatomical variations between the mesial and distal parts. The different optical behavior of the two enamels (HRi and HFO) is visible, not in the cervical part where enamel is very thin (around 0.3 mm) but in the middle and incisal thirds where enamel is thicker. The difference in color is perceivable **(a)** and the black and white version **(b)** emphasizes the difference in value.

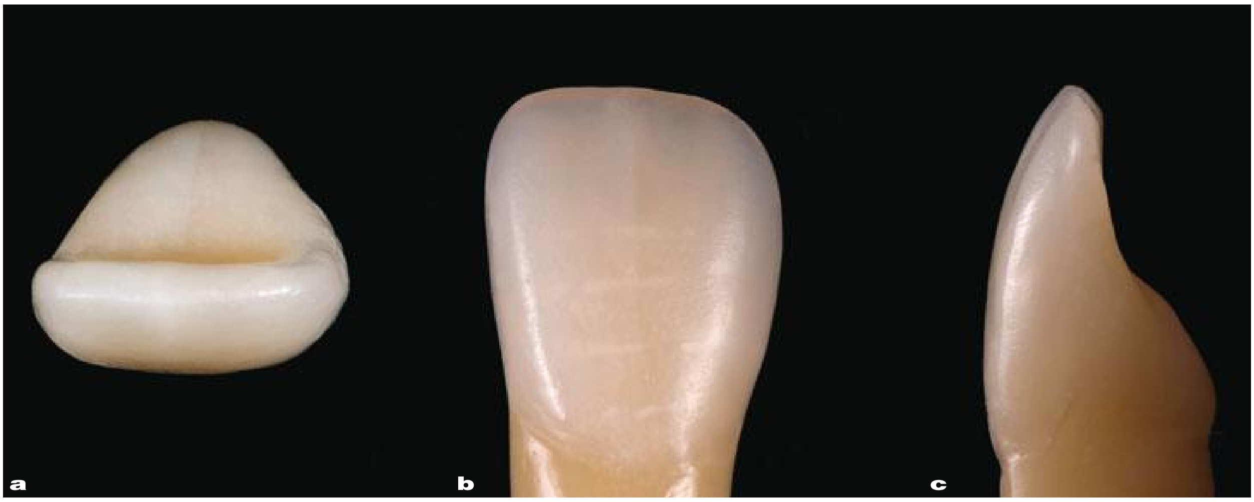


Fig 18 Composite build up tooth completed and observed in different positions. From incisal view **(a)** the differences between the two enamels are visible in the palatal surface as well. Frontal view **(b)** with flashes with bouncers, and **(c)** lateral view.

Conclusions and clinical relevance

The high refractive index enamel (HRi) composite exhibits different optical behavior compared to a traditional refractive index composite (HFO). When increasing the thickness of HFO enamel composites, both the value and the chroma of the dentinal substrate decreases, similarly to many composites. In contrast, HRi enamel composite behaves more like natural enamel as by increasing the thickness of the enamel layer, the value increases too. For both materials tested, increasing the thickness reduced the translucency. For thickness equal or higher than 0.5 mm, color difference of the two composites is clinically perceptible.

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