Evaluation of Translucency and Opalescence of Human Enamel

การประเมินความโปร่งแสงและความเหลือบมัวของเคลือบฟันมนุษย์

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ABSTRACT

The objective of this study was to evaluate translucency and opalescence of human enamel from different types of tooth. Human enamel slabs were prepared from 32 upper incisors, 17 upper canines and 34 upper premolars. There were divided into 5 groups; 3 groups of 1 mm-thick upper incisor, upper canine and upper premolar and also the other 2 groups of 0.8 mm-thick upper incisor and 1.2 mm-thick upper premolar (The 1.2 mm-thick upper incisor and 0.8 mm-thick upper premolar could not be fabricated because of limitation of the method). All enamel slabs were determined translucency and opalescence using spectrophotometer. The results showed that within the 1 mm-thick specimen, upper incisor enamel possessed the higher translucency compared to upper canine and premolar enamel and also emitted the greater opalescence than upper premolar enamel. ($p < 0.05$) Alteration of thickness of enamel only 0.2 mm might change the translucency but not affected the opalescence. The results were useful as reference values for dental restorative materials.

บทคัดย่อ

วัตถุประสงค์ของการศึกษาคือประเมินความโปร่งแสงและความเหลือบมัวของเคลือบฟันมนุษย์จากฟันหลายชนิด โดยเตรียมแผ่นเคลือบฟันมนุษย์จากฟันตัดกลางบนจำนวน 32 ซี่ ฟันเขี้ยวบนจำนวน 17 ซี่ และฟันกรามน้อยบนจำนวน 34 ซี่ จากนั้นแบ่งกลุ่มทดลองออกเป็น 5 กลุ่ม ประกอบด้วย 3 กลุ่ม ที่มาจากฟันตัดกลางบน ฟันเขี้ยวบน และฟันกรามน้อยบน ที่มีความหนา 1 มม. และ 2 กลุ่มที่เหลือประกอบด้วย ฟันตัดกลางบนความหนา 0.8 มม. และฟันกรามน้อยบนความหนา 1.2 มม. (ไม่สามารถเตรียมฟันตัดกลางบนความหนา 1.2 มม. และฟันกรามน้อยบนความหนา 0.8 มม.ได้จากข้อจำกัดทางวิธีวิจัย) วัดค่าความโปร่งแสงและความเหลือบมัวด้วยเครื่องสเปกโตรโฟโตมิเตอร์ ผลการทดลองพบว่ากลุ่มชิ้นทดลองความหนา 1 มม. ชิ้นเคลือบฟันจากฟันตัดกลางบนให้ความโปร่งแสงมากกว่าชิ้นเคลือบฟันจากฟันเขี้ยวบนและฟันกรามน้อยบน และยังให้ความเหลือบมัวมากกว่าชิ้นเคลือบฟันจากฟันกรามน้อยบนด้วย ($p < 0.05$) การเปลี่ยนแปลงความหนาของเคลือบฟันเพียง 0.2 มม. อาจมีผลต่อการเปลี่ยนแปลงความโปร่งแสง แต่ไม่มีผลกระทบต่อความเหลือบมัว ผลของการศึกษานี้มีประโยชน์เพื่อใช้เป็นค่าอ้างอิงสำหรับวัสดุบูรณะทางทันตกรรม

Key Words: Translucency, Opalescence, Enamel

คำสำคัญ: ความโปร่งแสง ความเหลือบมัว เคลือบฟัน

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Introduction

Nowadays esthetic considerations play an importance role for restorative dentistry. Optical properties are one of the considerations influencing on restoration of anterior teeth. (Villarroel et al., 2009) At the incisal third of anterior teeth which is mostly composed of enamel, opalescence and translucency are the key optical properties of enamel to achieve esthetic restoration.

Opalescence is an optical property, occurring due to light scattering of the shorter wavelengths of the visible spectrum, giving the material a bluish color under reflected light and orange/brown color under transmitted light (Lee et al., 2005). Even though, several studies investigated opalescence of resin composites (Arimoto et al., 2010; Yu et al., 2009a; Yu, Lee, 2009; Song et al., 2008; Lee et al., 2006), few studies; however, determined that of natural teeth (Schmeling et al., 2012a; Lee, Yu, 2007) and only one study determined that of human enamel (Lee, Yu, 2007).

Translucency is another crucial optical property. It is an appearance attribute of material which allows light to pass through it (Paravina, Power, 2004) Translucency was commonly determined by light transmission, contrast ratio and translucency parameter (TP value) (Brodbelt et al., 1981; Ikeda et al., 2005; Ikeda et al., 2004; da Costa et al., 2009; Yu, Lee, 2008). However, TP value was widely used to evaluate translucency of dental materials (Schmeling et al., 2012b; Ikeda et al., 2005; Ikeda et al., 2004). Therefore TP value of enamel should be investigated to compare the TP value of dental materials. There are several studies determining the translucency of human teeth (Brodbelt et al., 1981; Hasegawa et al., 2000; Yu et al., 2009b; Li et al., 2010). Nevertheless, only one study investigated TP value of human enamel (Yu et al., 2009b).

Type of tooth may influence on the opalescence and translucency of human enamel. Moreover, there has been no study determining opalescence and translucency of human enamel from various types of tooth.

Objective of the study

The aim of this study was to evaluate translucency and opalescence of human enamel from various types of tooth as reference values for dental restorative materials. The null hypothesis was TP and OP values of enamel from different tooth types were not difference.

Methodology

Experimental design

Type and thickness of enamel were independent parameters in the study. Because we focused on visible area of patient smile, there were three types of teeth: upper incisor, upper canine and upper premolar including in the study. If the same optical properties of various types of teeth were found, it would be useful that we would not pay attention to the factor for the further studies.

Regarding the thickness of enamel, we mainly concentrated on 1 mm-thick enamel which might represent the thickness of incisal edge of the tooth. Moreover, two additional groups (0.8 mm-thick incisor enamel and 1.2 mm-thick upper premolar enamel) were done to determine the effect of thickness on the optical properties of enamel. Unfortunately, 1.2 mm-thick upper incisor and 0.8 mm-thick upper premolar could not be done. For

incisal enamel, they were so thin that we could not cut them to 1.2 mm in thickness without dentin. For premolar enamel, if we cut them to 0.8 mm in thickness, diameter of the specimens was less than that of aperture of spectrophotometer thus affecting to measurement of their optical properties.

Preparation of enamel slab

The study was done after the protocol had been approved by the Ethics Committee of the Faculty of Dentistry/Faculty of Pharmacy, Mahidol University. The teeth were collected and stored as anonymous specimens from Thai patients who could not be identified their age.

Human enamel slabs were prepared from 32 upper incisors, 17 upper canines and 34 upper premolars. The inclusion criteria were that the extracted teeth were free from enamel defect, caries and restoration. Discolored teeth such as tetracycline were excluded from the study. After storage in 0.1 % thymol solution (Schmeling et al., 2012a), facial enamel of the teeth was separated longitudinally by a low speed diamond saw (Isomet™, Buehler Ltd., Lake Bluff, IL, United States). The further step was modified from previous study. (Li et al., 2010). The cutting side of enamel slab was polished until obtaining a smooth plane with 1 or 0.8 or 1.2 ± 0.05 mm-thick (depending on 5 groups; Table 1) using silicon carbide papers (P360, P800, P1200, P2400, and P4000; Buehler™, Buehler Ltd., Lake Bluff, IL, United States) attached to a polishing machine (RotoPol-21, Struers, Copenhagen, Denmark) in wet condition to prevent drying of enamel slab. The facial surface was kept intact for simulating surface of natural enamel. The thickness of specimen was measured from height of contour of facial surface to cutting side using a digital micrometer (Mitutoyo, Mitutoyo CO, Kawasaki, Japan). The cutting side of enamel slab was detected to the point that no dentin was observable using a measuring microscope (Nikon, MM-400, Nikon Corporation, Tokyo, Japan). In addition, surface roughness of the polished surface of 6 enamel slabs was evaluated by a profilometer (SE-2300 Kosaka Laboratory, Tokyo, Japan) for calibration of the polishing step. (average roughness; Ra < 0.20 μm). Enamel slabs were immersed in distilled water at 37^0C until the measurement of optical properties.

Determination of translucency and opalescence

All specimens were removed from distilled water and blot dried. Within 15 seconds after blot dried, spectrophotometer (HunterLab, ColorQuest XE, Hunter Associates Laboratory Inc, Virginia, USA) based on standard illuminant source D65, 10^0 standard observer, diffuse/8^0 geometry, including UV component of illumination and specular component of reflection, was used to measure the optical properties according to the CIE (Commission Internationale de l'Eclairage) L*a*b* color scale. L* is the lightness, where 100 is white and 0 is black, a* is the red-green coordinate and b* is the yellow-blue coordinate. A positive a* or b* refers to a red or a yellow color, respectively. Specimens were measured in reflectance and transmittance mode. In reflectance mode, specimens were measured over white and black background for translucent data and also measured over zero-calibrating box for opalescent data. Aperture size of reflectance measurement is 4 mm. Since the real aperture size is 25 mm of transmittance measurement and enamel specimens are smaller than that size, opaque cardboard specimen support plates with central windows of the same as aperture of

reflectance measurement (4 mm) was made. This modification was performed according to previous study. (Lee, Yu, 2007) The measurement was repeated 3 times for each specimen.

With regarding to determination of translucency, translucency parameter (TP value) was calculated by the equation, $TP = [(L^*_w - L^*_B)^2 + (a^*_w - a^*_B)^2 + (b^*_w - b^*_B)^2]^{1/2}$. Subscript W and B refer to value of color coordinates against white and black background, respectively.

To investigate opalescence, opalescence parameter (OP value) was selected and the formula is $OP = [(CIE_{aT}^* - CIE_{aR}^*)^2 + (CIE_{bT}^* - CIE_{bR}^*)^2]^{1/2}$. Subscript T and R indicate transmittance and reflectance color (under zero calibrating box background) respectively.

Statistical analysis

Determination of translucency and opalescence of various types of human enamel

Data of TP and OP from various tooth types and thickness of teeth was analyzed by Kolmogorov-Smirnov test and Levene's test in order to check normal distribution and homogeneity of variance, respectively. After that, one way ANOVA and Scheffe's multiple comparisons were done due to unequal number of sample in each group. The level of significance was at 0.05.

Determination of association between opalescence and translucency in human enamel

Pearson's correlation coefficient between OP and TP of each type of tooth was determined. The level of significance was at 0.05.

Results

Translucency and opalescence of human enamel from various types of tooth

Translucency and opalescence (TP and OP) of human enamel are demonstrated in Table 1.

Parameter: type of tooth within 1 mm in thickness

Descending order of translucency and opalescence of the enamel with 1 mm in thickness was as follows: upper incisor > upper canine > upper premolar.

For translucency, statistical significance was found between upper incisor and upper canine and also between upper incisor and upper premolar. Furthermore, statistical significance was also found in the group of opalescence only between 1 mm-thick upper incisors and premolars ($p < 0.05$).

Parameter: thickness

From the data, it was likely that the thicker the thickness of the specimen, the lower the translucency and the greater the opalescence. Statistical analysis showed that vary in thickness of the specimens resulted in alteration of translucency significantly only in the upper incisors, not in the upper premolars. Whereas vary in thickness of the specimens had insignificant influence on the opalescence ($\alpha = 0.05$).

Relation between opalescence and translucency of human enamel

For the pooled data (every type of enamel), there was no significant correlation between OP and TP ($p > 0.05$). However, the difference of result was found when determining the correlation of both values within each type of enamel.

At a constant 1 mm-thick enamel, high correlation between OP and TP of the upper incisors was found (r = 0.72), whereas there was intermediate correlation between OP and TP of the upper canines and upper premolars. The relationship between OP and TP of the 0.8 mm-thick upper incisors and the 1.2 mm-thick upper premolars could not be established. In addition, when pooled data of only 1 mm-thick enamel was determined, intermediate to high correlation was found (Table 2, Figure 1, 2).

The significant correlation coefficients (r) derived from all groups were positive values. These meant that the relation between OP and TP was in the same direction. The higher the OP value, the higher the TP value and vice versa (Table 2, Figure 1, 2).

Table 1 TP and OP of various types of human enamel.

Type of enamel	Thickness (mm)	Code	n	Mean TP	Mean OP
Upper incisor	1	UI-1	17	28.8 (3.1) [b]	19.4 (1.3) [a]
Upper canine	1	UC-1	17	25.6 (2.5) [c]	18.7 (1.4) [a, b]
Upper premolar	1	UP-1	17	23.0 (2.1) [c, d]	17.8 (1.3) [b]
Upper incisor	0.8	UI-0.8	15	31.8 (2.6) [a]	18.1 (1.4) [a, b]
Upper premolar	1.2	UP-1.2	17	20.5 (2.2) [d]	18.9 (1.2) [a, b]

Standard deviations are in parentheses.

The same superscript lower case letters in the same column indicate no significant differences ($p > 0.05$).

Table 2 Relation between opalescence and translucency of human enamel

Type of enamel	p value	Pearson correlation coefficient (r)
Pooled data	0.060	-
UI-1	0.001	0.72
UC-1	0.044	0.49
UP-1	0.028	0.53
UI-0.8	0.670	-
UP-1.2	0.186	-
1 mm-thick Enamel	< 0.001	0.70

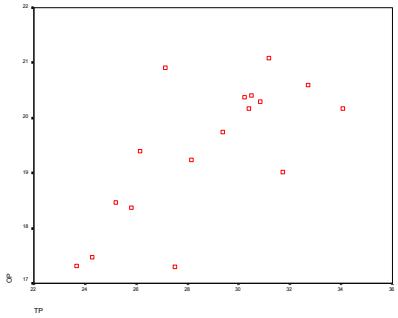

Figure 1 Scatter plot between OP and TP values of UI-1.

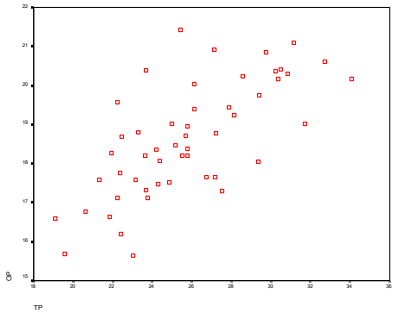

Figure 2 Scatter plot between OP and TP values of 1 mm-thick enamel.

Discussion

Translucency of human enamel

Enamel is a translucent substance since when light strike the enamel surface some light transmits through enamel whereas the other reflects from the surface or scattering.

The null hypothesis that TP values of various types of enamel were not difference was rejected. Within the 1 mm-thick enamel, incisal enamel provided statistically higher TP (28.8) compared to canine (25.6) and premolar enamel (23.0). The possible reason might involve the surface curvature related to direction of enamel rod.

As structure of enamel, the inorganic content is primarily hydroxyapatite crystals that contribute significantly to scattering resulting in effect on optical properties. The fundamental organization units of the crystal of enamel are called enamel rods. They run generally perpendicular direction to the surface of dentin. (Nanci, 2008; Paravina, Powers, 2004). The surface of dentin is parallel to the surface curvature of the enamel therefore the difference of surface curvature of enamel from different types of tooth results in dissimilar directions of enamel rods and thus possibly providing the distinct translucency. In our study, upper premolar and canine provided higher surface curvature than upper incisor. Therefore they provided different orientation of enamel rod and consequently possessed different translucency.

Another possible reason was about the aprismatic layer at the uppermost surface of enamel. Whittaker (1982) found that the thickness of aprismatic layer varied from the tooth types. Therefore the enamel from different tooth types of our study might possess dissimilar light transmission according to different thickness of aprismatic layer contributing to distinct translucency.

One study measured the TP of enamel for representation of translucency using 3 mm-aperture spectrophotometer. The method from that study was comparable to that of our study (Yu et al., 2009b). The result of the study showed that TP of 1 mm-thick human enamel was 18.7 which the value was lower than that of our study (23-29) using 4 mm-aperture size. The bigger aperture size resulted in the higher translucency. (Yu et al., 2009b). That might be why the TP of enamel in our study was higher.

Two studies revealed that thickness had major influence on translucency of resin composites. (Arimoto et al., 2010; Schmeling et al., 2012b). Additionally, for relation between TP and thickness of human enamel, one study revealed that TP of 0.8 mm-thick premolar was higher than that of 1 mm-thick premolar enamel (Li et al., 2010). According to the present study, TP value of 0.8 mm-thick upper incisor was significantly higher than that of 1 mm-thick upper incisor. This was in agreement with the previous study. However, there were no significant differences of TP values between 1 mm-thick and 1.2 mm-thick upper premolar. One study reported that correlation between translucency and thickness was expressed by exponential decreasing functions. (Kamishima et al., 2006). It was possible that relation between translucency and thickness as a range between 0.8 – 1 mm might be determined in the higher curve of exponential graph. Therefore alteration of translucency was found even if the difference of thickness was only 0.2 mm. While the level of thickness was between 1 – 1.2 mm, that relation might be located in the lower curve of exponential graph. Consequently, alteration of translucency was not observed.

Opalescence of human enamel

When light strikes natural teeth, scattering and transmission play a major role that causes the phenomenon of opalescence of teeth (Primus et al., 2002; Paravina, Powers, 2004). One study specified

key factors which maximized opalescence. 1) the presence of one or more internal phases (~380 – 500 nm), 2) a large difference in the refractive index between the matrix and the internal phases, 3) a high dispersion in one or all of the internal phases (Primus et al., 2002). Therefore opalescence of natural teeth can be seen since the presence of fine-grained hydroxyl apatite crystals behaves like internal phases within the object and generates that optical property.

The null hypothesis that OP values of various types of enamel were not difference was rejected. The result of opalescence of 1 mm-thick enamel was in the order; upper incisor (19.4) > upper canine (18.7) > upper premolar (17.8). However, there was significant difference of OP values only between upper incisor and premolar. The possible reason might also be the dissimilar directions of enamel rods from various types of enamel (Lee, Yu, 2007). Since the rods contained hydroxyl apatite crystals, they have an influence on the scattering of light affecting to the opalescence. Furthermore, different thickness of aprismatic layer from various tooth types of enamel (Whittaker, 1982) might also affect the opalescence in the same role as its effect to the translucency.

The result showed that the differences of OP values of enamel from various tooth types were lower than their differences of TP values. OP formula is calculated from only Δa and Δb (Kobashigawa, Angeletakis, 2001) whereas TP formula involves not only that factors but also ΔL (Schmeling et al., 2012b; Ikeda et al., 2005; Ikeda et al., 2004). In our study, ΔL was sensitive parameter and change of the value was also quite higher than that of Δa or Δb therefore alteration of TP was higher than that of OP. This reason should also be used to explain why there were much more groups of enamel specimen possessing comparable OP value.

Within each type of enamel (upper incisor and upper premolar), alteration of thickness only 0.2 mm did not influence OP values. This might also be due to the formula of OP value. Although no study has investigated relation of opalescence and thickness of enamel, Arimoto et al. (2010) investigated that relation of resin composites which might be used to compare with our study. The study reported that all of the 2 mm-thick resin composites provided OP value higher than 1 mm-thick resin composites. Nevertheless, only one brand of resin composite provided higher OP values when alteration of thickness from 0.5 to 1 mm, whereas the others provided similar values. From mentioned above, they might be inferred that adequate alteration of thickness might influence on opalescence of substances.

In the US patent, 1 mm-thick resin composites providing the OP value higher than 9 were regarded as opalescent (Kobashigawa, Angeletakis, 2001). However, it was not clear that what the criterion determining that value was. In our study, OP values as 17.8-19.4 might be preferably used for reference values.

One study reported mean OP value of human enamel ranged from 0.9-1.3 mm in thickness using 3 mm-aperture spectrophotometer was 22.9 (Lee, Yu, 2007). Whereas in the present study, OP values of 1 mm-thick human enamel ranged from 17.5-19.5 mm using 4 mm-aperture spectrophotometer. The difference of OP values between two studies might be due to the aperture size of spectrophotometer. The possible reason was supported by the same study. (Lee, Yu, 2007).

Relation between opalescence and translucency

Previous studies investigated relation between TP and OP values in resin composite materials. They study revealed that correlation between TP and OP was material dependent (Lee et al., 2005; Arimoto et al., 2010). In addition, the study revealed that the higher the OP, the lower the TP (Arimoto et al., 2010).

Since no study has determined the relation of OP and TP in human enamel, we attempted to investigate this topic. The results showed that there were significant intermediate to high correlations between OP and TP within UI-1, UC-1, UP-1 and all 1 mm-thick enamel group with positive r. It meant that opalescence was directly proportional to translucency in several groups of human enamel. The result was difference from the previous study determining the relation of the values with resin composites.

Limitation of the study

According to our method that teeth were collected from anonymous specimens, the difference in age of teeth would impact the optical properties of enamel.

Conclusion

Within limitations of this study, it was concluded that type of teeth influenced on translucency and opalescence of human enamel. Upper incisor enamel possessed the higher translucency compared to upper canine and premolar enamel and also emitted the greater opalescence than upper premolar enamel as 1 mm in thickness. Alteration of thickness of enamel only 0.2 mm might change the translucency but not affected the opalescence. The results were useful as reference values in order to compare translucency and opalescence between enamel and dental restorative materials

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