A Preliminary Research into Clinical Semi-permeability Tolerance in the Field of Dental Rehabilitation

H Xia[1], F Xiong[2]

ABSTRACT

Objective: *To study clinical semi-permeability tolerance level in the field of dental restoration.*
Method: *Vita 95 enamel porcelain powder was adopted and 6.0% used as the control transmissivity. Discoid porcelain plates with different transmissivity, namely increasing transmissivity (0.25%, 0.5%, 1.0%, 1.5%, 2%, 2.5%, 3%, 3.5%, 4% and 4.5%) and decreasing transmissivity (-0.25%, -0.5%, -1.0%, -1.5%, -2%, -2.5%, -3% and -3.5%) were made. Forty observers judged these according to six grades: same, similar, slightly different, visibly different, recognizable and significantly different, and under the observation conditions of a neutral grey background and 45°/0° lighting. The judgment results were analysed statistically.*
Results: *When the transmissivity of the control porcelain plates was 6.032%, and the transmissivity of test porcelain plates decreased by 1% or increased by 3%, observers could find slight differences between the test samples and the control samples. When transmissivity of test samples decreased by 2.5% or increased by 4.5%, observers thought that the two porcelain plates belonged to different orders of magnitude.*
Conclusions: *Under the experimental conditions, the upper and lower limits of clinical semi-permeability tolerance were 3% and 1%, respectively.*

Keywords: Clinical tolerance, dental porcelain, semi-permeability, transmissivity

Una Investigación Preliminar sobre la Tolerancia a la Semipermeabilidad Clínica en el Campo de la Rehabilitación Dental

H Xia[1], F Xiong[2]

RESUMEN

Objetivo: *Estudiar el nivel de tolerancia a la semipermeabilidad clínica en el campo de la restauración dental.*
Método: *El polvo de porcelana de esmalte Vita 95 fue adoptado y 6.0% fue usado como control de la transmisibilidad. Se hicieron platos de porcelana discoides con diferente transmisibilidad, es decir, transmisibilidad creciente (0.25%, 0.5%, 1.0%, 1.5%, 2%, 2,5%, 3%, 3,5%, 4% y 4,5%) y transmisibilidad decreciente (-0.25%, -0,5% -1,0% -1.5%, -2%, -2,5%, -3% y -3.5%). fueron hechas. Cuarenta observadores emitieron juicios sobre ellos, de acuerdo con seis grados: iguales, similares, ligeramente diferentes, visiblemente diferentes, reconocibles, y significativamente diferentes, con condiciones de observación de un fondo gris neutro y una iluminación de 45°/0°. Los resultados del juicio fueron analizados estadísticamente.*
Resultados: *Cuando la transmisibilidad de las placas de porcelana de control fue de 6.032% y la transmisibilidad de las placas de porcelana de prueba placas disminuyó un 1%, o aumentó un 3%, los ob-*

From: [1]Department of Maxillofacial Surgery and [2]Department of Prosthodontics, West China College of Stomatology, Sichuan University, Chengdu 610041, China.

Correspondence: Dr F Xiong, Department of Prosthodontics, West China College of Stomatology, Sichuan University, 14, 3rd Section, Ren Min Nan Lu, Chengdu 610041, China. E-mail: xofa@163.com

DOI: 10.7727/wimj.2016.057

servadores pudieron encontrar ligeras diferencias entre las muestras de prueba y las muestras de control. Cuando la transmisibilidad de las muestras de prueba disminuyó 2.5% o aumentó 4.5%, los observadores pensaron que las dos placas de porcelana pertenecían a diferentes órdenes de magnitud.
Conclusiones: *Bajo las condiciones experimentales, los límites superiores e inferiores de la tolerancia clínica semi permeabilidad fueron 3% y 1%, respectivamente.*

Palabras claves: Tolerancia clínica, porcelana dental, semipermeabilidad, transmisibilidad

West Indian Med J 2015; 64 (5): 534

INTRODUCTION

Chromatic aberration (ΔE) is often adopted to measure differences between two colours. Due to the limited discrimination ratio of human eyes, it is of vital significance for observers to establish chromatic aberration tolerance to judge differences between two colours. When chromatic aberration between two colours is smaller than the chromatic aberration tolerance, it is regarded that the two colours cannot be distinguished by human eyes, and the two colours appear the same to observers. Chromatic aberration tolerance in the chromatic system of different countries varies. In China, it is: chromatic series: $\Delta E < 3$; achromatic series: $\Delta E < 1.5$ (1, 2). This is the theoretical basis for chromatic research of most Chinese scholars. In the field of dental restoration, chromatic aberration tolerance has also been applied widely in terms of clinical and scientific research. However, scholars have not yet achieved an agreement about the tolerance standards. Ragain (3) thought that it was clinically unacceptable when $\Delta E > 2.75$; Ruyter *et al* (4) thought that ΔE3.3 was clinically acceptable. Douglas and Brewer (5) thought that the clinically acceptable ΔE should be within 2Δ4. Johnston and Kao (6) thought that ΔE was acceptable when it was within 3.7, and that the average of the unacceptable ΔE was 6.8.

Apart from colours, semi-permeability (ΔT) is of equal importance to the simulation of the appearance of natural teeth in the field of dental restoration (7, 8). Some scholars believe that semi-permeability is the most important second optical property (9). However, the difference of semi-permeability has no corresponding clinical tolerance, and the clinical semi-permeability tolerance has not yet been studied. Currently, most research into semi-permeability focusses on measurement of permeability of dental tissues and materials. Brodbelt *et al* (10) measured the transmission coefficient of enamel and found out that the transmission coefficient was about 0.481 mm^{-1} when the wavelength was 525 nm. Vaarkamp *et al* (11) thought that when the wavelength of light source was 633 nm, transmissivity of enamel was 35%, and transmissivity of dentin was 5%. Research by Xiong *et al* (12) suggested that when the visible wavelength was within the range of 400Δ760 nm, the transmission coefficient range of dentin was 0.0817~ 0.1009 mm^{-1}; and the transmission coefficient range of dentin was 0.0418~0.0482 mm^{-1}. Both are higher than the corresponding enamel porcelain and dentin of Vita veneering porcelain. Apart from transmission performance of enamel and dentin, there has been a lot of research into overall transmissivity of natural teeth. Research by Hasegawa *et al* (13) suggested that transmission parameter (TP) of central incisors in the mouth of the living body gradually decreased from the incising end to the neck part. In other words, semi-permeability gradually decreases. Chen (14) measured the TP value of central incisors in the mouth of the living body and found that the value of TP in one-third of the central area was obviously lower than those on two sides. Thus, central semi-permeability is lower than those on two sides. Xiong *et al* (15) found that transmissivity of central incisors of the upper jaw of the living body averaged within the range of 0.1568~0.6058%. The transmissivity of central incisors showed an increasing trend along with the increase in age. In the field of dental restoration, a lot of research has been conducted on the semi-permeability of porcelain materials (16, 17). Thickness has the greatest influence on transmissivity of porcelain (18).

Based on the above literature review of semi-permeability, dental porcelain plates of different transmissivity were prepared. Visual analysis was conducted to find the clinical tolerance of the semi-permeability difference, ΔT, and the authors hope that this research can contribute to the study of natural teeth and prosthesis.

METHODS

Thickness of porcelain samples is extremely sensitive to changes of thickness (18). From the preliminary experiment, it could be seen that transmissivity of test samples was highly sensitive to changes of thickness. Considering the convenience of making experimental samples and the control of chromatic aberration, this experiment used Vita 95 enamel porcelain to make experimental samples, change the transmissivity by changing the thickness of experimental samples and control the variation range of permeability within 2~11%. At the same time, the chromatic aberration was controlled to stay at the minimum level based on the achromatic nature of enamel porcelain.

Experimental grouping

Samples with the transmissivity of 6.0% were adopted as the control group. A series of samples of different transmissivity were made in two directions, namely the increase and decrease of transmissivity. Semi-permeability between samples in the test group and the control group is shown in Table 1.

Table 1: Semi-permeability (ΔT) between test and control groups

Increase group	**Control**	**A1**	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**	**A9**	**A10**
Transmissivity (%)	6.0	6.25	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10	10.5
ΔT (%)	0	0.25	0.5	1	1.5	2	2.5	3	3.5	4	4.5
Decrease group	**Control**	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**B8**		
Transmissivity (%)	6.0	5.75	5.5	5.0	4.5	4.0	3.5	3	2.5		
ΔT (%)	0	-0.25	-0.5	-1	-1.5	-2	-2.5	-3	-3.5		

Making and measurement of experimental samples

Spatulate porcelain powder was made according to the powder-to-liquid ratio required by the product. It was injected into the circular hole of the self-made plastic mold to slight overflowing. The porcelain powder was used to compress the oscillator and keep it oscillating. Filter paper was used to absorb excessive moisture. A sharp blade was used to remodel excessive materials on the surface of the mold in the horizontal direction. It was left standing for ten minutes. After that, it was demolded and sintered according to standard procedures in the vacuum porcelain furnace produced by Sinosteel LIRR (Luoyang Institute of Refractories Research; Luoyang, China). Sintered samples were polished with waterproof abrasive paper, 400#, 600#, 800#, 1000# and 1200#, in turn, to keep the two sides smooth. The diameter was about 15 mm, while the thickness could be adjusted according to different transmissivity. The experimental samples were put under the stereoscopic microscope to observe whether there were obvious defects on the surface. If there were, the samples were eliminated. After ultrasonic cleaning, samples were dried for future use.

The PR-650 spectrum scanning instrument was used to measure the transmissivity of the central part of every sample. After each measurement, the sample was rotated by 45°. In the second measurement, samples were rotated in the same way. Then, the measurement was repeated twice, according to the above method. After four measurements of each sample, the average of results was worked out. At the same time, the dominant wavelength and the colour purity of experimental samples against the black and white background were measured and recorded.

Visual appraisal

Visual observation conditions

Light source: Adopt the D65 simulative light source with the colour temperature of 6500K in the standard light source box of Gretag Macbeth, especially for The Judge® II visual appraisal, to stand for the north window light.

Lighting and observation direction: 45°/0° recommended by CIE (photos were exposed to light at an angle of 45° and observed at the vertical direction).

Observation background environment: Samples were observed in the standard light source box especially for The Judge® II visual appraisal. The inner wall of the light source box featured the Munsell N7 neutral grey low-gloss surface so as to avoid the influence of the background colour on visual appraisal. The observation took place in the darkroom to avoid the disturbance of other light rays excluding the standard light source.

Observers: Observers were a group of 40 young doctors (18 males and 22 females) aged from 24 to 35 years and with certain clinical colorimetric experiences.

Making of the sample support for visual appraisal

The sample support is shown in Fig. 1. The support surface of the test samples and the surface of the light box were put at an angle of 45° to ensure that the light source on the top of the light box shone on samples at an angle of 45°. The support surface featured Munsell N7 neutral grey to avoid disturbing the visual appraisal. The background of the test and control samples featured black and white stripes.

Fig. 1: Sample support for visual appraisal.

Rank of observation results

Observation results can be divided into six psychological sensation ranks:

Same: Observers thought that the two test samples were totally the same in the same field of view.

Similar: Observers felt the two test samples were the same, but were not sure that they were totally the same.

Slightly different: Observers could observe the differences between two test samples.

Visibly different: Observers could tell the difference between two test samples without careful observation.

Recognizable: Observers could obviously tell the difference between two test samples, and the difference was relatively huge.

Significant difference: Observers could not only see the significant difference between two test samples, but also felt the difference was unacceptable.

Based on the statistical analysis of the results, the relationship between ΔT and psychological sensation rank could be established. The corresponding ΔT of "slightly different" was adopted as the semi-permeability clinical tolerance.

Experiment operation

The light was cast on the test samples at an angle of 45° during the experiment and eyes kept vertical to the test samples. The deviation angle between the two should not exceed 10°. The test samples were disks with a diameter of 1.5. The distance from the two eyes to the test sample was about 40 cm. The observation condition was kept at a 10° view field.

Control samples were put on the sample support and the serial numbers were randomly added to the test samples. Operators could randomly pick up test samples and put near the control samples. However, observers could not touch the test samples to avoid being influenced by the different thickness of the samples. Observers could repeatedly compare the test samples and the control samples until a satisfactory psychological sensation rank was achieved. Since the visual appraisal did not take long, observers would not suffer from visual fatigue. However, if observers' eyes felt tired then they could take a rest at any time, and continue appraising after recovery.

RESULTS

Transmittance, transmittance difference, dominant wavelength and colour purity against the black and white backgrounds of test samples are shown in Table 2. The transmittance of control samples was 6.032%. The transmittance of the remaining test samples increased or decreased in turn, with the highest being 10.59% and the lowest being 2.426%. The value in brackets in Table 2 is the rank difference between the actually measured value and the set value of transmittance of various experimental samples. The absolute value averaged at 0.041%, with the minimum value as 0.005% and the maximum value as 0.091%.

Distribution of test samples on the CIE 1964 Chromaticity Diagram (white backing) is shown in Fig. 2. Chromaticity coordinate of various test samples concentrated on the CIE 1964 Chromaticity Diagram.

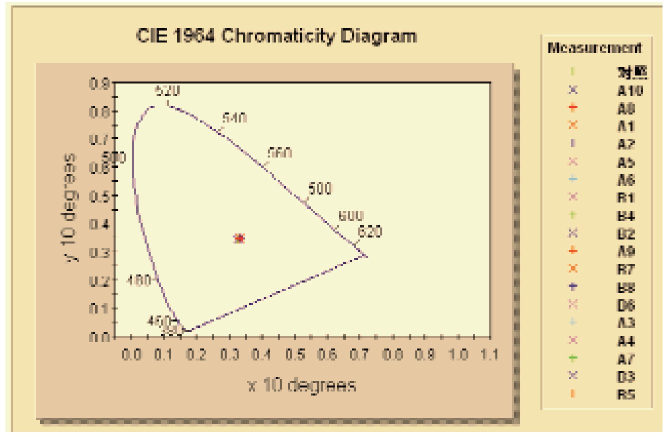

Fig. 2: Distribution of test samples on the CIE 1964 Chromaticity Diagram (white backing).

Test results of 40 observers are shown in Table 3. The statistical treatment of the test results adhered to the conventional statistical methods in psychophysical statistics. In other words, observers adopted 75% of the sum of selection times of every sample over the total discrimination times as the rank difference to determine the boundary. The statistical results of the experiment are shown in Table 4. When the transmittance of control samples was 6.032%, and the transmittance of test samples decreased by 1% or increased by 3%, observers thought that there was a slight difference between test samples and control samples.

Table 2: Transmissivity, semi-permeability, dominant wavelength and excitation purity of test samples

Group	T (%)	ΔT (%)	White background λD (nm)	P_e (%)	Black background λD (nm)	P_e (%)
B8	2.426 (+0.074)*	3.606	581.0	80.88	580.3	78.45
B7	2.981 (-0.019)*	3.051	581.0	80.88	580.2	78.67
B6	3.572 (+0.072)*	2.460	580.9	80.47	580.2	78.22
B5	4.041 (+0.041)*	1.991	580.7	80.31	580.1	78.01
B4	4.528 (+0.028)*	1.504	580.7	80.14	580.0	77.71
B3	5.010 (+0.010)*	1.022	580.7	80.15	580.0	77.66
B2	5.452 (-0.048)*	0.580	580.7	80.01	579.9	77.55
B1	5.755 (+0.005)*	0.277	580.7	80.10	580.0	77.43
Control	6.032 (+0.032)*	0	580.6	79.90	579.9	77.08
A1	6.280 (+0.030)*	0.248	580.6	79.94	579.9	77.22
A2	6.508 (+0.008)*	0.476	580.7	79.97	579.9	77.62
A3	7.009 (+0.009)*	0.977	580.6	79.80	579.9	77.12
A4	7.535 (+0.035)*	1.503	580.6	79.89	579.8	77.16
A5	8.037 (+0.037)*	2.005	580.6	79.60	579.8	77.11
A6	8.539 (+0.039)*	2.507	580.6	79.73	579.8	77.07
A7	9.091 (+0.091)*	3.059	580.6	79.69	579.8	77.09
A8	9.473 (-0.027)*	3.441	580.6	79.65	579.8	76.85
A9	9.913 (-0.087)*	3.881	580.5	79.63	579.8	76.69
A10	10.59 (+0.090)*	4.558	580.5	79.54	579.8	76.76

*: Value in brackets is the difference between the measured value and the set value

T: Transmissivity; ΔT: semi-permeability; λD: dominant wavelength; Pe: excitation purity

Table 3: Psychological sensation rank of test samples

Test samples	ΔT (%)	Same (times)	Similar (times)	Slightly different (times)	Visible difference (times)	Recognizable (times)	Significant difference (times)
B8	3.606	0	0	0	0	4	36
B7	3.051	0	0	0	0	10	30
B6	2.460	0	0	0	3	12	25
B5	1.991	0	0	1	5	24	10
B4	1.504	0	0	4	24	11	1
B3	1.022	0	2	9	22	7	0
B2	0.580	1	16	14	8	7	0
B1	0.277	2	22	10	6	0	0
A1	0.248	18	14	8	0	0	0
A2	0.476	8	18	14	0	0	0
A3	0.977	6	19	14	1	0	0
A4	1.503	5	15	17	2	1	0
A5	2.005	2	8	22	8	0	0
A6	2.507	2	7	18	13	0	0
A7	3.059	0	3	22	10	5	0
A8	3.441	0	1	15	19	5	0
A9	3.881	0	1	12	24	3	0
A10	4.558	0	0	4	26	8	2

ΔT: semi-permeability

Table 4: Psychological sensation value of semi-permeability

	Same (times)	Similar (times)	Slightly different (times)	Visible difference (times)	Recognizable (times)	Significant difference (times)
Lower limit (%)	–	0.580	1.022	1.504	2.460	3.606
Upper limit (%)	0.977	1.503	3.059	3.881	4.558	–

DISCUSSION

In order to determine the clinical tolerance of translucency, an ideal experiment should cover the whole transmittance range involved in the restoration field. The range can be divided into several ranks from the high ones to the low ones. A series of test samples with an increasing ΔT should be established. At the same time, attention should be paid to whether the difference between the upper and lower limit of transmittance has an influence on experimental results during the comparison of transmittance of the same rank. Therefore, the test sample of every rank gets two comparison series with transmittance higher or lower than that of the control sample. It was hard for the current conditions to reach the above requirements. Therefore, the experiment was conducted within a limited range.

As shown in Table 2, the span of the transmittance of test samples was not huge. Considering the sensitivity of human eyes, a preliminary experiment showed that there was no need to set samples with a huge difference. At the same time, the colour difference of samples will also increase when transmittance difference is huge, which will influence the experimental results.

The actual measured value of transmittance of various experimental samples was relatively close to the set value (Table 2). The average difference between the actually measured value and the set value of the transmittance was far smaller than the rank difference between the control samples and the test samples. Therefore, the making of the experimental samples was basically in line with the set requirements. The value of the rank difference between the control samples and the test samples will directly influence the visual appraisal precision. The more detailed the range difference division, the higher the precision of the visual appraisal.

In the experiment, ΔT set several ranks, namely 0.25%, 0.5%, 1.0%, 1.5%, 2%, 2.5%, 3% and 3.5%, and was divided into two series with increasing and decreasing transmittance, respectively. Among the experimental samples with increasing transmittance, two ΔT ranks – 4% and 4.5% – were increased. The rank difference, ΔT, set by the experiment, is the relatively precise and correct value which can be achieved under the current conditions. If the rank difference is further detailed, it is impossible for the current conditions to ensure the consistency between the transmittance of test samples and the set value.

The perceptible characteristics of colours include value, hue and saturability. The latter two are called chromaticity. Chromaticity can be expressed by chromaticity coordinate, or by dominant wavelength and colour purity. The latter is more direct. Therefore, this experiment used dominant wavelength and colour purity to express the colour characteristics of samples. From Table 2, it can be seen that dominant wavelength and colour purity of experimental samples against the same background were almost the same. The average dominant wavelength against the white background was 580.6789 nm, and the maximum difference was 0.5 nm. The average dominant wavelength against the black background was 579.9421 nm and the maximum difference was 0.5 nm.

The average colour purity against the white background was about 80.015% and the maximum difference was 1.34%. The average colour purity against the black background was 77.446% and the maximum difference was 1.98%. The chromaticity discrimination ability of human eyes includes discrimination ability of dominant wavelength and colour purity. Human eyes' discrimination ability of the medium section of the wavelength spectrum is relatively strong, and strongest especially around blue green (490 nm) and yellow (590 nm). The resolution threshold around 590 nm was about 1 nm. The colour purity discrimination ability of human eyes was related to the value of colour purity.

When the colour purity was low, the discrimination threshold was 5%; when the colour purity was high, the discrimination threshold was 2% (3). Since the maximum difference value of the dominant wavelength and the colour purity in this experiment was lower than the discrimination threshold of human eyes, chromaticity of experimental samples was consistent. In this experiment, the formula, was not used to calculate chromaticity because when the transmittance of samples changes, the value also changes; ΔL^* changes can lead to the increase of ΔE, but chromaticity of various samples shows no obvious changes. From Fig. 1, it can be seen that chromaticity coordinate of various experimental samples concentrates on the CIE 1964 Chromaticity Diagram, which almost overlap into one point.

When the transmittance of control samples was 6.032%, and the transmittance of test samples decreased by 1% or increased by 3%, observers thought that there was slight difference between test samples and control samples; when the transmittance of test samples decreased by 2.5% or increased by 4.5%, observers thought that the two kinds of samples did not belong to the same order of magnitude. In Table 4, there is no lower limit value of the same rank difference and no upper limit value of the large rank difference. The reason was that while observing samples with decreasing transmittance, only some observers thought that there were test samples the same as the control samples. Similarly, while observing samples with increasing transmittance, only some observers thought that there were samples that differed greatly from control samples. Since the number of observance cases of the two groups of psychological sensation value was too small, the value of ΔT of the two groups of rank difference was not marked in Table 4.

Based on further analysis of experimental results, the upper limit value of ΔT corresponding to every psychological sensation rank was larger than the lower limit value of ΔT. The reason might be related to the making of the samples. From Table 2, it can be seen that the difference of colour purity between samples in Group B with decreasing transmittance and control samples is 0.98% (white background) and 1.59% (black background); while the difference of colour purity between samples in Group A with increasing transmittance and control samples is 0.36% (white background) and 0.39% (black background). Though the difference of colour purity between samples in Group A and B and control samples was lower than human eyes' discrimination threshold of colour purity, the colour purity difference of Group B was larger than that of Group A. Whether the difference will influence observers still calls for further research. While studying discrimination of Chinese eyes about surface differences on achromatic colour series, Sun *et al* (2) found that ΔE of the lower limit was smaller than that of the higher limit. The findings were similar in this experiment. This suggests that, apart from the making of samples, there are some other possible factors which might lead to the generation of the phenomenon. When human eyes observe psychophysical quantities, such as colours and translucency, the subjective observation results are directed. Thus, human eyes are especially sensitive to changes in certain direction. Of course, all the above is just speculation. The specific causes are awaiting further exploration.

The observation results of transmittance were divided into six psychological sensation ranks. Based on the research into chromatic aberration tolerance both at home and abroad, this experiment used the rank of "slightly different" as the translucency clinical tolerance. Under the conditions of the experiment, samples with the transmittance of 6% were used as control samples. The upper limit of the translucency clinical tolerance can be regarded as 3%, while the lower limit is 1%. Though the discrimination research into chromatic aberration of achromatic colour series suggested that the chromatic aberration value discriminated by human eyes showed no significant difference in terms of high value, medium value or low value, it calls for further study whether the conclusion can be promoted to the discrimination of translucency.

CONCLUSIONS

In this experiment, 40 observers used samples with transmissivity of 6% as control samples, and observed test samples with increasing and decreasing transmissivity, whose ΔT was 0.25%, 0.5%, 1.0%, 1.5%, 2%, 2.5%, 3%, 3.5%, 4% and 4.5%, respectively. They were classified according to the six psychological sensation ranks: same, similar, slightly different, visibly different, recognizable and significantly different. Slightly different was adopted as the semi-permeability clinical tolerance. Results suggested that under the conditions in the experiment, the upper and lower limit of the semi-permeability clinical tolerance were 3% and 1%, respectively.

ACKNOWLEDGEMENTS

This work was supported by Science and Technology Support Program of Sichuan, grant no. 2014FZ0073 and Science and Technology Support Program of Sichuan (subproject of key technology of biological bone materials development), grant no. 2014SZ0019-8.

REFERENCES

1. Sun XR, Lin ZD, Zhang JY, Lin ZX, Jing QC, Guo SQ. An experimental study of discrimination of surface colour differences by the Chinese eye. Acta Psychological Sinica 1996; **28:** 9−15.
2. Sun XR, Lin ZD, Zhang JY, Lin ZX, Jing QC. An experimental study of discrimination of surface colour differences on achromatic colour series by the Chinese eye. Acta Psychological Sinica 1995; **27:** 231−40.
3. Ragain JC, Johnston WM. Minimum colour differences for discriminating mismatch between composite and tooth colour. J Esthet Restor Dent 2001; **13:** 41−8.
4. Ruyter IE, Nilner K, Moller B. Colour stability of dental composite resin materials for crown and bridge veneers. Dent Mater 1987; **3:** 246−51.
5. Douglas RD, Brewer JD. Acceptability of shade differences in metal ceramic crowns. J Prosthet Dent 1998; **79:** 254−60.
6. Johnston WM, Kao EC. Assessment of appearance match by visual observation and clinical colorimetry. J Dent Res 1989; **68:** 819−22.
7. Joiner A. Tooth colour: a review of the literature. J Dent 2004; **32:** 3−12.
8. Kelly JR, Nishimura I, Campbell SD. Ceramics in dentistry: historical roots and current perspectives. J Prosthet Dent 1996; **75:** 18−32.
9. Terry DA, Geller W, Tric O, Anderson MJ, Tourville M, Kobashigawa A. Anatomical form defines colour: function, form and aesthetics. Pract Proced Aesthet Dent 2002; **14:** 59−67.
10. Brodbelt RHW, O'Brien WJ, Fan PL, Frazer-Dib JG, Yu R. Translucency of human dental enamel. J Dent Res 1981; **60:** 1749−53.
11. Vaarkamp J, ten Bosch JJ, Verdonschot EH. Propagation of light through human dental enamel and dentin. Caries Res 1995; **29:** 8−13.
12. Chao YL, Xiong F, Zhu ZM. Comparison of the semi permeability of enamel, dentin and Vita finishing. Shanghai Oral Med 2007; **16:** 640−3.
13. Hasegawa A, Ikeda I, Kawaguchi S. Colour and translucency of in vivo natural central incisors. J Prosthet Dent 2000; **83:** 418−23.
14. Chen L. Chinese Sichuan area and population of natural teeth shadeguide colorometry research [Dissertation]. Chengdu: Sichuan University.
15. Xiong F, Chao YL, Zhu ZM. Translucency of newly extracted maxillary central incisors at nine locations. J Prosthet Dent 2008; **100:** 11−7.
16. Heffernan MJ, Aquilino SA, Diaz-Arnold AM, Haselton D, Stanford C, Vargas M. Relative translucency of six all-ceramic systems. Part I: core materials. J Prosthet Dent 2002, **88:** 4−9.
17. Heffernan MJ, Aquilino SA, Diaz-Arnold AM, Haselton D, Stanford C, Vargas M. Relative translucency of six all-ceramic systems. Part II: core and veneer materials. J Prosthet Dent 2002, **88:** 10−5.
18. Xiong F, Chao YL, Zhu ZM. Effect of the thickness ratio of the ceramic layer and the mixed ratio of the ceramic powder on the semi permeability of the decorative porcelain. Practic J Oral Med 2008; **24:** 482−7.
19. Tang SQ. Colorimetry. Beijing: Beijing Institute of Technology; 1990: 82−5.