Effects of Background, Direction and Intensity of Ambient Light, Measuring Position, and Adjacent Teeth, on Anterior Tooth Colour Measurement *In Vitro*

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Objective: *To investigate the effects of different background colours (black, white or pink), direction and intensity of ambient light, measuring position, and the adjacent teeth, on the* in vitro *colour measurement of maxillary anterior teeth, using the Minolta CR-321 colorimeter.*
Methods: *Ten extracted human maxillary central incisors were selected. A fibre-optic light MI-150 was used as the ambient illuminant. Teeth were irradiated from a 3- or 12-o'clock direction. L*a*b* values of seven sites on the labial surfaces were obtained by means of the Minolta CR-321 colorimeter, using three background colours, with or without the adjacent teeth. The recorded data were analysed with two-tailed Student* t *tests and analysis of variance ($\alpha = 0.05$).*
Results: *The ambient light did not affect the colour measurement of anterior teeth, regardless of the presence or absence of the adjacent teeth. There were no statistically significant differences in L*a*b* values at the same position under different background colours, except ΔE_{12} (colour difference between site 1 and site 2) between black and white backgrounds. ΔE_{12} (under black background), ΔE_{13} and ΔE_{15} were greater than 1.5, while the others were lower than 1.5.*
Conclusion: *The background, ambient light and the presence of adjacent teeth did not affect the colour measurement of anterior teeth using the Minolta CR-321 colorimeter* in vitro*. The inherent disadvantages of using the naked eye during clinical visual shade assessment may be overcome by the colorimeter.*

Key words: *background colour, colorimeter, colour measurement,* in vitro*, tooth colour*

There are two main methods for tooth colour measurement, including the human visual shade assessment and electronic-instrument-based measurement. Many factors, such as ambient light and background colours, influence visual shade assessment. With advances in technology, electronic instruments for colour assessment have become a relatively accurate means of visual shade assessment. Several studies have compared human visual shade assessment with electronic instrument shade assessment[1,2]. Three human visual shade assessments matched in only 26.6% of the investigations, while three spectrophotometric shade selections matched in 83.3% of the investigations[1]. Although there were statistical differences among the different instruments, the maximum predicted error could hardly be detected by human eyes and the colour data were comparable[3]. It has been determined that electronic instrument shade analysis is more accurate and reproducible compared with human visual shade assessment[1].

However, there are also many factors to be considered in electronic-instrument-based measurement, such as the inherent properties of teeth and the conditions under which shade assessments are conducted. It is bet-

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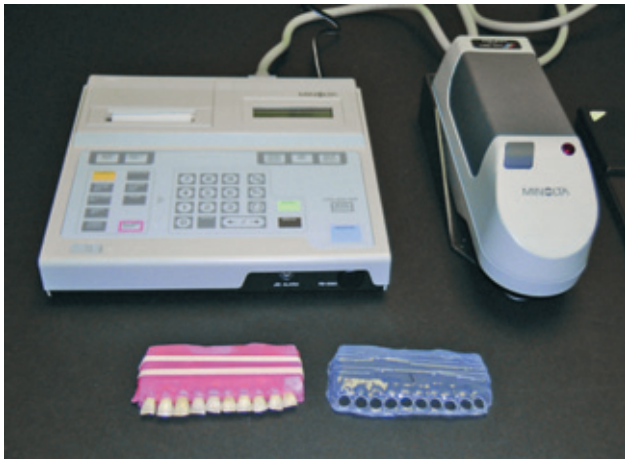

Fig 1 Minolta Chroma Meter CR-321.

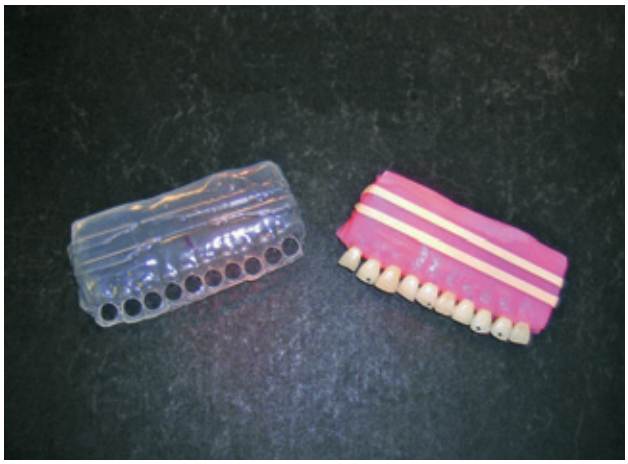

Fig 2 Position guidance set-up.

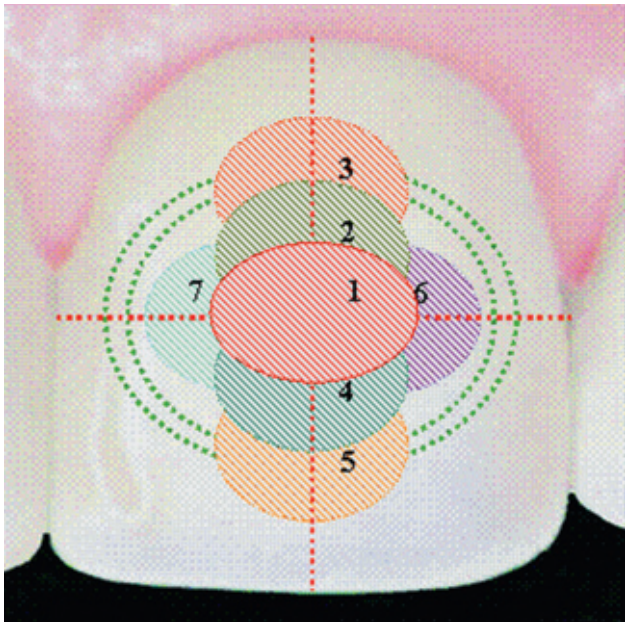

Fig 3 Determination of seven measuring sites.

ter to use full-spectrum light while making colour measurements[4]. There are few reports on the potential influence of various factors, including background colours, intensity and direction of ambient light, adjacent teeth, and tiny movements of the instrument's detecting head[5], on the results of colour measurement when using a colorimeter. The present study aimed to investigate whether these factors could affect the colour measurement using a colorimeter.

Materials and methods

Ten extracted human maxillary central incisors were selected. These teeth were extracted because of periodontitis (sanctioned by the Ethics Committee of Wenzhou Medical College). The criteria for tooth selection were: normal anatomical shape, and no apparent defects, restorations, staining, excessive abrasion or caries on the labial surfaces. The Minolta Chroma Meter CR-321 with D65 (Konica Minolta, Tokyo, Japan; Fig 1) was used in the present study. The diameter of the detecting head is 3 mm, and the optical geometry is 45/0-degrees. A fibre-optic light MI-150 (Dolan-Jenner, Boxborough, MA, USA), which is a 150-Watt quartz halogen illuminator capable of delivering nearly 30,000 footcandles of high intensity illumination, was employed. This is a complete fibre-optic illumination system. The detecting head of the MI-150 fibre-optic light was positioned 20 mm away from the centre of the measuring device. Incident light irradiated from the 3-or 12-o' clock direction of the teeth (the incisal edge pointing downward) at 45 degrees to the vertical. The light intensity was modulated to 0 W, 50 W, 75 W, 100 W, 125 W and 150 W.

The present study was conducted in a dark room. The distance between the palatal surfaces of the teeth and unglazed paper plate backgrounds was 1 cm. The teeth were kept moist in a container with normal saline. When taken for colour measurement, just enough excess water was removed with filter paper, to simulate the moist surrounding in the oral cavity. Colours of the background paper plates were white, black and pink.

Before the experiment, the Minolta Chroma Meter CR-321 was calibrated using a normal white plate. Recalibration was performed during colour measurements as needed. During colour measurements, the detecting head maintained contact with the observation site using a position guidance set-up (Fig 2). L*a*b* values of the following seven sites (Fig 3) on the labial surface of each tooth were measured: the centre of the tooth, 1 mm deviation to the apical, 1 mm deviation to the incisal edge, mesial and distal angulations, and at deviations of 2 mm to the apical, and 2 mm to the incisal edge.

Table 1 CIE L*a*b* values of different positions under the three background colours

Background	Position	L* (mean ± SD)	a* (mean ± SD)	b* (mean ± SD)
Black	1	53.00 ± 2.26	-2.04 ± 0.21	2.28 ± 1.49
	2	54.69 ± 2.84	-2.07 ± 0.49	4.25 ± 0.72
	3	55.30 ± 3.64	-1.97 ± 0.47	5.12 ± 1.25
	4	52.54 ± 2.75	-1.83 ± 0.38	1.83 ± 1.68
	5	51.65 ± 3.27	-1.80 ± 0.53	1.59 ± 2.01
	6	53.63 ± 3.00	-1.89 ± 0.48	1.92 ± 1.51
	7	54.21 ± 2.67	-2.13 ± 0.36	1.81 ± 1.87
White	1	53.87 ± 2.53	-2.10 ± 0.53	2.88 ± 1.27
	2	54.70 ± 2.99	-1.84 ± 0.38	3.48 ± 0.99
	3	55.26 ± 3.95	-1.91 ± 0.34	5.11 ± 1.55
	4	52.79 ± 2.54	-1.73 ± 0.26	1.77 ± 1.88
	5	52.04 ± 2.92	-1.55 ± 0.45	1.66 ± 2.14
	6	53.72 ± 2.78	-1.83 ± 0.45	2.05 ± 1.74
	7	54.37 ± 2.60	-1.94 ± 0.38	1.86 ± 1.55
Pink	1	53.79 ± 3.05	-1.96 ± 0.36	2.68 ± 1.58
	2	55.07 ± 3.04	-2.02 ± 0.25	3.91 ± 0.99
	3	55.56 ± 4.14	-2.06 ± 0.27	5.41 ± 1.41
	4	52.86 ± 2.70	-1.77 ± 0.32	2.08 ± 1.49
	5	52.21 ± 2.80	-1.68 ± 0.40	1.59 ± 2.08
	6	54.02 ± 2.73	-1.96 ± 0.38	2.05 ± 1.58
	7	54.59 ± 2.40	-2.15 ± 0.24	2.00 ± 1.49

There were a total of three measurements at each of the seven locations on the teeth. The detecting head was turned 90 degrees clockwise after each measurement. Teeth were fixed in a plane such that the contiguous relationship was similar to the alignment of teeth in the oral cavity. After the colour of each tooth was measured, a total of five teeth were removed from the experimental site, creating intervals of five edentulous spaces. The colour of the remaining teeth (each of which had no adjacent tooth), was measured. The five excluded teeth were then substituted into the positions of those upon which colour measurements had been performed, and colour measurements were repeated. Extreme caution was taken to preserve the integrity of the enamel of the teeth.

The CIE LAB system was used to record the colour data. As an international colour metering standard, it defines a colour space (L*a*b*) in which L* represents lightness, a* represents the chromaticity coordinate for red–green (+a* = red direction; -a* = green direction), and b* represents the chromaticity coordinate for yellow–blue (+b* = yellow direction; -b* = blue direction)[6]. The colour difference (ΔE) between two objects can be calculated according to the following equation: $\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$ within the CIE LAB colour system[7].

The data analysis software used was the SPSS 11.5 statistical package (SPSS, Chicago, IL, USA). Analysis of variation (ANOVA) was used to analyse the differences in colour values among different positions under three background colours, and also the differences in colour values with different intensities of incident light. Pairwise comparison of group means (Student *t* test) was used to examine the differences between two directions with or without adjacent teeth, the differences with and without adjacent teeth in the same direction, and with the same intensity of incident light (the data of site 1 was chosen in this analysis). The significance was set to $\alpha = 0.05$.

Results

Table 1 depicts CIE L*a*b* values of different positions under three background colours. There was no difference in the values of L*,a*,b* for the same position under different background colours ($P > 0.05$). In Table 2, ΔE_{12} (the colour difference between site 1 and site 2) shows a statistically significant difference between black and white backgrounds ($P < 0.05$). The significant colour difference between site 1 and site 2 under a black background, site 1 and site 3, and site 1 and site 5, could be recognised by the naked eye ($P < 0.05$), while other

Table 2 ΔE (mean ± SD) between site 1 and other sites under the three backgrounds, and the ANOVA results

ΔE	Black background	White background	Pink background	Among the three backgrounds F	*P*
ΔE_{12}	2.83 ± 1.03	1.22 ± 0.59	2.15 ± 1.56	5.06	0.01
ΔE_{13}	4.08 ± 1.31	3.39 ± 0.98	3.98 ± 1.20	1.01	0.38
ΔE_{14}	1.42 ± 0.93	2.03 ± 0.88	1.73 ± 0.91	1.14	0.34
ΔE_{15}	2.68 ± 1.24	2.91 ± 1.50	2.65 ± 0.97	0.14	0.87
ΔE_{16}	1.15 ± 1.78	1.90 ± 0.94	1.37 ± 0.71	1.62	0.22
ΔE_{17}	1.82 ± 1.17	2.01 ± 1.15	1.87 ± 0.88	0.08	0.92

Table 3 Result of Student *t* test of colour difference on three backgrounds between site 1 and the other six sites compared with ΔE = 1.5

Position	Black background	White background	Pink background
ΔE_{12}	+	-	-
ΔE_{13}	+	+	+
ΔE_{14}	-	-	-
ΔE_{15}	+	+	+
ΔE_{16}	-	-	-
ΔE_{17}	-	-	-

+, $P < 0.05$; -, $P > 0.05$

differences were not easily recognisable (Table 3). There was no significant colour difference with different intensities of incident light and different directions of irradiation ($P > 0.5$). Also, there was no significant difference of colour values among the teeth with and without adjacent teeth using the same intensity of incident light ($P > 0.1$).

Discussion

Compared with visual analysis, instrumental measurement is a more rapid, stable, quantitative and repeatable method for *in vitro* colour measurement of maxillary anterior teeth. However, there are many factors affecting colour measurement using a colorimeter. These include the position from which colour measurement is made[4], light conditions[8], the integrity of the tooth, pulp vitality, caries, discolouration, dehydration[9] and the geometric design of the instruments.

The colour of natural teeth is created by a combination of light that is reflected and scattered by tooth enamel and the underlying dentine layer[10,11]. The light refraction and scattering properties of enamel can affect perception of tooth colour[10,12]. Therefore, colour measurement may be influenced if there is caries or other demineralisation on the tooth surface. The present study was designed by carefully protecting the enamel integrity of the teeth to exclude the influence of enamel.

In the present study, background had no effect on colour measurement while using the Minolta CR-321 colorimeter ($P > 0.05$). A possible reason could be that there was no reflection under any of the backgrounds used in a dark room. Also, there was little light penetrating the tooth, because the detecting head was in contact with the tooth surface. It was demonstrated that the Minolta CR-321 Chroma Meter provides standardised measuring conditions. Thus it would eliminate a number of influential factors, such as

variations in lighting and human colour perception in the present study, which can significantly affect the accuracy of colour assessment[13].

In addition, the transparent membrane ensured the accurate position of the detecting head while making colour measurements. Light leaks away at the edges of the detecting head that are in contact with the irregular surface of the tooth. This causes volume reflection and lateral displacement. For these reasons, light value is reduced and there is a deviation of measurements for hue and chroma. Consistency in colour measurement was displayed by the colorimeter while using a special position-fixing set-up[14].

In the present study, the distance between the palatal surfaces of the teeth and a paper plate background was 1 cm. The diameter of the detecting head was 3 mm. A transparent membrane with an aperture ensured that the position of the detecting head was immovable, and also ensured that the detecting head and tooth surface remained vertical while making colour measurements. Thus, the influence of background on colour measurement was prevented. If the diameter of the detecting head is reduced in future studies, the above problem should be eliminated. Further study is also required to determine the effect of background colour on colour measurement when using the Minolta Chroma Meter CR-321 in an illuminated room.

Colour is darker at the cervical area of a tooth than at the middle and incisal areas, and there are significant differences in colour perception among the three areas[5,15]. Many clinicians use the colour value of the labial central site in the middle third as the tooth's colour coefficient[2,16,17]. In the present study, a total of seven sites were determined, including the central site of the middle third of the tooth. The purpose was to see if there was a significant difference in colour measurement when there was minute movement of the detecting head. Based on the theory that the minimal colour difference that can be recognised by the naked eye is 1.5 ΔE[18,19], $\Delta E = 1.5$ was compared with every colour difference in Table 3. ΔE_{12} (under a black background), ΔE_{13} and $\Delta E_{15} > 1.5$, which suggested that colour differences may be recognised by the naked eye when the detecting head is moved more than 2 mm vertically. Therefore, even the smallest movement in colour measurement position should be avoided when using the Minolta Chroma Meter CR-321 clinically.

Further investigation is required to determine if the colour value of the labial central site in the middle third of the tooth can be used as the tooth's colour coefficient. If possible, nine zones and three hierarchies of colour selection should be used.

There is no apparent influence of light in the 75–300 footcandles range on visual colour assessment[20]. Is there any influence of light intensity or direction on colour measurement when making instrumental measurements? When colour measurement is conducted under ambient light conditions, the light is reflected, scattered and absorbed. The light scattered in the dentine probably goes into the detecting head and influences the accuracy of colour assessment. However, in the present study, there was no detectable influence on colour measurement when light of different intensities was irradiated from the 3- or 12-o' clock directions at 45 degrees to the vertical. This may be relevant to the optical geometric design of the Minolta Chroma Meter CR-321, which is 45/0-degrees. The light source of the detecting head has thirty annular optical fibres, which can irradiate in a 360-degree direction from the margin of the detecting head at 45 degrees. Therefore, it may provide uniform light intensity in every direction. A receiving inductor inside the detecting head only receives the light that is reflected in a vertical direction. The ambient light, owing to scattering and refracting, could seldom reach the receiving inductor.

The presence or absence of adjacent teeth had no influence on colour measurement. This was probably because the light that is reflected by the adjacent teeth seldom got into the colour measuring area of the detecting head while making instrumental measurements.

Conclusions

The background, ambient light or adjacent teeth did not affect the colour measurement of anterior teeth using the Minolta CR-321 colorimeter *in vitro*. The inherent disadvantages of using the naked eye in visual shade assessment may be overcome by using the Minolta CR-321 colorimeter clinically. Owing to the significant difference observed when the detecting head moved more than 2 mm vertically ($\Delta E > 1.5$), care should be taken to avoid minute changes in colour-measuring positions. Nine zones and three hierarchies of colour selection can enhance the accuracy of colour-matching artificial teeth.

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