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Colour Assessment in Dentistry

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Abstract

The colour of teeth is of considerable importance to the general population and the social and psychological impact of tooth discolouration is becoming increasingly less tolerated. A plethora of tooth-whitening systems (both for professional use and for use in the home) are now available and methods to assess the efficacy of such systems are required. In this paper an imaging system is described that can take reproducible images of patients' teeth and methods are described for the colorimetric analysis of these images. The results of a clinical trial indicate that the imaging system that has been developed is effective for the clinical evaluation of tooth whiteness.

1 Introduction

The colour of teeth is of considerable importance to the general population and the social and psychological impact of tooth discolouration is becoming increasingly less tolerated. It has been estimated, for example, that 28% of adults in the UK are dissatisfied with the appearance of their teeth [1] and that 34% of adults in the USA are similarly dissatisfied [2]. A more recent survey in the UK reported that up to 50% of adults perceived that they had some tooth discolouration [3]. Tooth colour is influenced by the intrinsic colour of the tooth and by any extrinsic stains that may form on the surface [4]. Intrinsic tooth colour is affected by the light-scattering and absorption properties of the enamel and dentine of the tooth itself but the enamel plays only a minor role through scattering at wavelengths in the blue range [5]. Fluorescence plays no role in tooth colour [5]. Stains result from poor dental hygiene and/or diet [6,7]. Tooth discolouration may be removed by a number of methods including the use of whitening toothpastes, dental scaling and polishing, bleaching, use of abrasive, and the use of crowns etc. Despite claims that tooth whitening may contribute to heightened self-esteem, improved oral hygiene and increased patient involvement with dentistry [8] its uptake by patients was relatively slow in the 1980s because of fears over the safety of cosmetic treatments. However, the development of tray-based bleaching systems in the late 1980s enabled dentists to achieve tooth whitening with minimal surgery time and greater patient tolerance [9]. Professional tooth whitening is now ubiquitous in dental care and there is a larger and growing market for home-based whitening systems. Home-based whitening systems typically contain low levels of bleaching agent (e.g. 3-6% hydrogen peroxide) that are self-applied to the gum via gum shields (trays), strips or paint-on products and require twice-per-day application for about two weeks [4]. The wide range of treatments available now necessitate that reliable and accurate methods be developed for the measurement of efficacy of whitening treatments.

Colour assessment of teeth has a long history because of the importance of colour assessment in the matching of prosthetics. Traditionally, visual colour determination is used based on visual comparison of the tooth with colour standards. Such colour standards (also known as shade guides) were developed from porcelain material to match the available shades of porcelain teeth. However, according to van der Burgt et al. there are three distinct disadvantages with the use of shade guides for colour assessment [10]. Firstly, the range of available colours in the shade guides is inadequate and the colour samples are not logically distributed [11]. Secondly, there is a lack of consistency among and between dentists in using the shade guides to match colours [10]. Thirdly, it is not possible to translate the results obtained from shade guides into CIE colour specifications. Figure 1 illustrates a typical shade guide that is called the VITA shade guide system. This system consists of 16 porcelain teeth samples that are normally arranged in a 1-dimensional order.

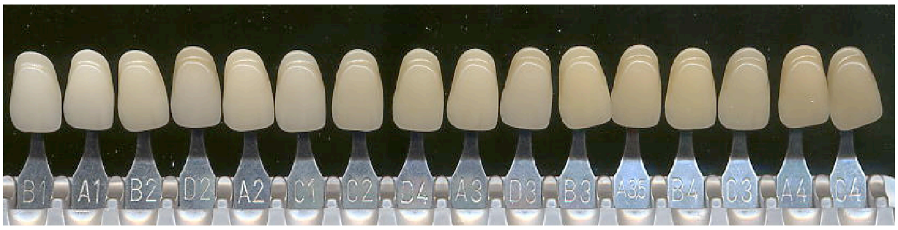

Figure 1: Vita shade guide used in visual assessments.

Table 1 shows the standard order in which the Vita shade guide samples or tabs are normally arranged and a revised order of decreasing whiteness obtained from a psychophysical study. The Vita shade guide does not present a perceptually linear whiteness scale because the perceptual colour difference between adjacent tabs in the scale is not a constant. Okubo et al. (1998) concluded that shade determination by visual means is inconsistent [12].

order	← Whiteness															
proposed	B1	A1	C1	B2	D2	A2	A3	D3	C2	D4	B3	A3.5	B4	C3	A4	C4
standard	B1	A1	B2	D2	A2	C1	C2	D4	A3	D3	B3	A3.5	B4		A4	C4

Table 1: Standard order of Vita shade tabs and revised order.

An alternative to visual colour assessment is the use of instrumental colour measurement. Contact-based colorimeters that can return CIE colour coordinates have been used for the measurement of tooth colour [13]. Seghi (1990) measured the repeatability of various spectrophotometers and colorimeters for colour measurement in dentistry and found that short-term repeatability was worse for translucent samples than for opaque samples [14]. It was also found that although the absolute values obtained for instruments of different optical geometry (for example, collimated illumination at 45 degrees compared with diffuse illumination) the relative values were the same [14]. However, it has been noted that the use of small-window colour-measurement instruments on turbid media can give incorrect values (CIELAB values are shifted towards the green and blue and to lower lightness) because of light loss at the edge of the sample being measured [15]. Variability in measurements made with contact-based instruments is also affected by the degree to which teeth are flat and if the instrument rocks on the tooth surface this can give rise to large errors. Indeed, van der Burgt et al. (1985) concluded that no reliable method for tooth colour determination or even colour comparison is available [10]. There has recently been considerable interest in the use of digital cameras for the measurement of tooth colour [16-18].

For instrumental colour assessment of teeth the issue of a suitable metric that corresponds to perceptual whiteness is important. Colorimeters, spectrophotometers, spectroradiometers and even camera systems can allow the computation of CIE XYZ or $L^*a^*b^*$ values [19]. Colour difference can be measured in terms of CIELAB colour difference values or ΔE. In the dental community there has been considerable interest in how close a match a porcelain prosthetic needs to be to adjacent teeth in order to be considered successful [20]. According to the results of Seghi et al. (1989) under ideal viewing conditions, ΔE^* values less than 1 are perceivable and ΔE^* values greater than 2 are discernable by most observers [21]. However, the ΔE^* value required for a match was 6-8 in another clinical study [22] and Khokhar et al., (1991) have suggested that a ΔE of 3.3 is acceptable in dentistry [23]. Based on a review of the literature Lee et al. (2001) have concluded that a ΔE of less than 1 cannot be perceived, less than 2 units is clinically acceptable and that greater than 3.3 units indicates an appreciable difference [20]. These studies were for the visual acceptability of a match between a porcelain prosthetic and natural teeth. For tooth whitening there is also the fact that for a patient to notice a difference induced by a treatment it is necessary to compare the colour of the teeth after the treatment with the colour before the treatment. If we take into account the imperfection of human colour memory we suggest that ΔE values close to 3 units will be required for in order for whitening to be noticed by most patients in practical situations. O'Brien et al. (1990) developed an equation for estimating CIELAB colour differences from pairs of Munsell hue (H), value (V) and chroma (C) terms since many dental shade guide standards are designated by these terms [24]. There has also been interest in the use of whiteness indices for tooth colour assessment [25,26].

The authors have developed a tooth-imaging system for the purpose of assessing tooth whiteness and have also developed a whiteness index that has been shown to correlate well with visual assessments of tooth whiteness [18,26]. In this paper the tooth-imaging system is described and some new results that validate its use in a clinical whitening trial are presented.

2 Experimental

The tooth-imaging system consists of a camera (Jai 3CCD) mounted in front of the patient and with annular illumination provided by LEDs. The distance between the patient (when their chin is on position of the chin rest) and the camera is approximately 12.5 cm (see Figure 2).

The lens and light source were fitted with polarising filters which were rotated to minimize specular reflections in the images. The most important property of the imaging system is that it can record consistent RGB values over time to allow comparisons to be made in tooth colour at the start of a clinical whitening trial with tooth colour during and after the trial. The LED light source is fitted with a controller that automatically controls the light intensity (compensating for changes in temperature). However, early experiments indicated that the consistency of the light source was not sufficient. Therefore, an image of a white card sample (obtained from the Macbeth ColorChecker) was taken and small manual changes to the light intensity were made to ensure that certain target RGB values were obtained. This calibration was carried out immediately before an image was taken of any patient.

Figure 2: Tooth-imaging system developed at University of Leeds and used in clinical trials.

A camera characterization model was used to subsequently allow camera RGB values to be converted to CIE XYZ values. The characterization model had three stages: (i) linearization, (ii) spatial correction, and (iii) transform. The linearization stage was to ensure that a linear relationship between camera RGB values and CIE Y values. Such linearization is commonly performed as part of camera characterization [19]. The second stage was to correct for lack of spatial uniformity in the imaging system (such lack of uniformity could result from problems with the light source, the lens, the camera CCD or various other parts of the imaging system). The following equation was used for the spatial correction,

$$R = (R_W - R_B)(R_i - R_{Bi})/(R_{Wi} - R_{Bi}) \qquad (1)$$

where R_W and RB are the average channel (camera *R*, *G* or *B* values) responses to the system for a spatially uniform white and black sample respectively (the black sample image was obtained with the lens cap in place), R_{Bi} and R_{Wi} are the channel responses at pixel *i* for the white and black sample, and R_i is the channel response at pixel *i* for the image that is to be corrected. The equation for spatial correction was derived from work by Sun and Fairchild [27]. The linearized and spatially corrected RGB values were then converted to CIE XYZ values using a linear transform whose coefficients were determined from 26 samples from the VITA 3D shade guide. The use of these samples in the development of the characterization performance limits the colour accuracy of the system to samples that are tooth coloured. The general form of the transform is presented as Equation 2.

$$\begin{aligned} X &= aR + bG + cB + d \\ Y &= eR + fG + gB + h \\ Z &= iR + jG + kB + 1 \end{aligned} \qquad (2)$$

Several replicates of the imaging system have been constructed and the actual values of the coefficients *a-l* in Equation 2 vary between the systems. However, for the system used in this study the following equation was used,

$$\begin{aligned} X &= -0.0588R + 0.2805G - 0.0663B + 8.5785 \\ Y &= -0.0986R + 0.3476G - 0.0827B + 7.7107 \\ Z &= -0.1843R + 0.2357G + 0.0886B + 10.0050. \end{aligned} \qquad (3)$$

A clinical whitening trial was conducted at the University of Leeds. Sixteen patients were recruited to take part in the study and were separated into test and control groups. The control group of eight patients used ordinary (non-whitening) toothpaste during the trial period. The test group used the Colgate Platinum Overnight whitening system (a tray-based system containing 10% carbamide peroxide) every night for 14 days. An image of each patient's teeth was obtained at the beginning of the trial period. QLF software (Inspektor Research Systems, The Netherlands), which is widely used in fluorescence image capture in dentistry, was applied to take images at 4, 7, 11 and 14 days into the trial that were aligned with the image taken at the beginning of the trial. Figure 3 illustrates the quality of the images that were taken.

Figure 3: Image for control patient before (upper left) and after (upper right) trial and for test patient before (lower left) and after (lower right) trial.

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MATLAB software was used to analyse the images. The software allowed nearly identical areas on the incisors to be specified in before and after images. The RGB values from these areas were averaged and then converted to XYZ values by the characterization model. The CIE XYZ values were subsequently converted to CIELAB values and various whiteness and yellowness indices. An experienced dental practitioner assessed the colour of the teeth using a VITA shade guide during every visit by the patient to have an image taken. These visual assessments enabled a comparison between the values obtained by the imaging system and more traditional methods.

3 Results

Figures 4-6 show the CIELAB values obtained from the imaging system averaged for control and test groups. From these figures it is evident that the CIELAB values remained approximately constant for the control group during the trial. The average CIELAB values (approximately L^* = 59, a^* = 6.5 and b^* = 17) are comparable with the measurements from other studies. Bosch and Coops (1995), for example, obtained L^* = 69.9, a^* = -0.22 and b^* = 17.9 averaged over 102 extracted incisors. Measurements of in vivo incisors for patients in the 30-49 age range gave L^* = 67.5, a^* = 4.1 and b^* = 18.4 [28]. The results for the test group show significant changes in b* and some change in L^*. The a^* value was relatively stable. The change in b^* is a reduction in b^* value which is most likely to be the result of a reduction in yellowness of the teeth during the whitening process.

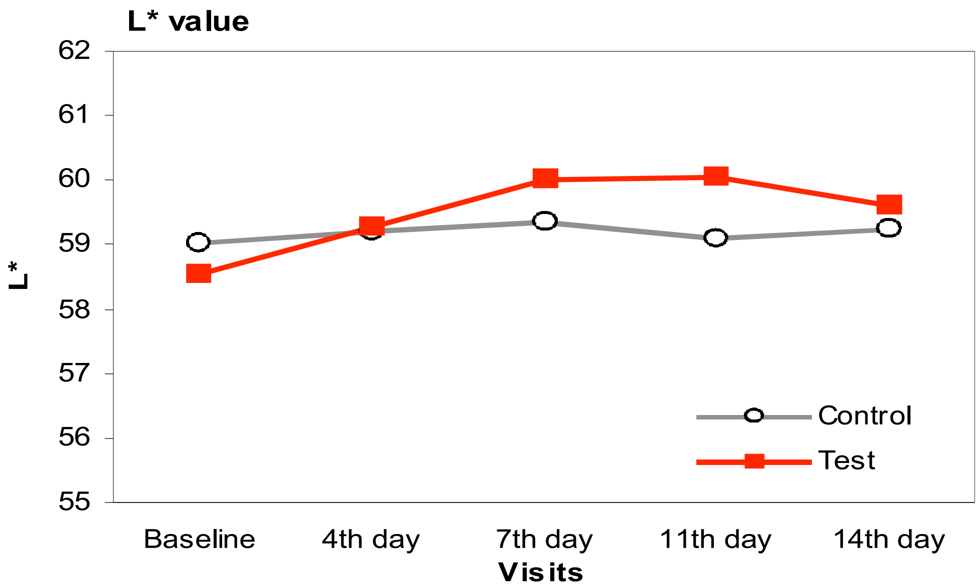

Figure 4: CIELAB L^* values for test and control groups

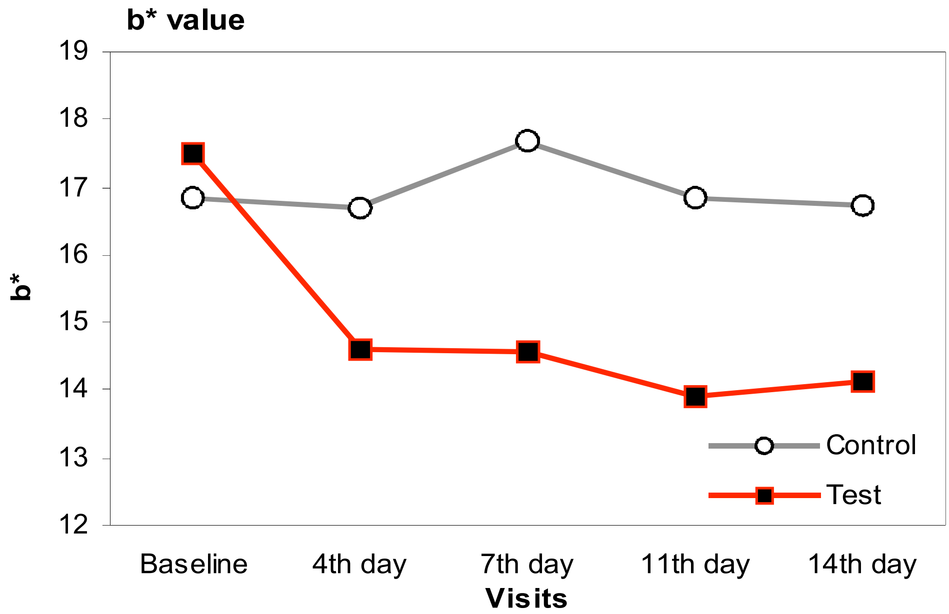

Figure 5: CIELAB b^* values for test and control groups.

The L^* value increased during the trial for the test group and therefore it is reasonable to conclude that during the whitening trial the test teeth became lighter and less yellow; both changes that would be associated with an increase in perceptual whiteness. Figure 7 shows the CIELAB ΔE^* values for the test and control group.

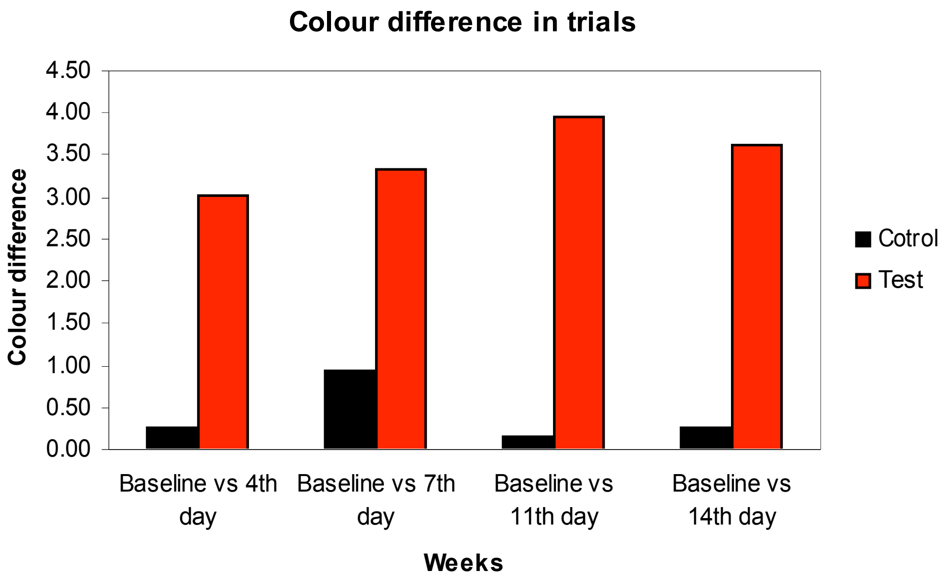

Figure 6: Mean CIELAB colour differences for test and control groups.

The effect of the whitening process resulted in a change of over 3 CIELAB units which is consistent with visible whitening. Most of this change took place within the first 4-7 days of the trial. The control group yielded colour differences less than 1 CIELAB unit. Figure 8 shows the change (in terms of VITA tabs) obtained from the visual assessments.

The visual assessment results (Figure 8) are also consistent with a substantial whitening effect of the Colgate Platinum Overnight system. Finally, the visual assessments were correlated with the changes in CIELAB values (Table 2). Table 2 shows strong correlation with each of the CIELAB coordinates suggesting that there is close agreement between the visual and instrumental results. The change in CIE whiteness formula [29] was also computed from the CIELAB values and this showed even stronger correlation with the visual results. However, the strongest correlation obtained was between the visual results and a modified whiteness formula [18] that has been specifically developed for the assessment of tooth whiteness.

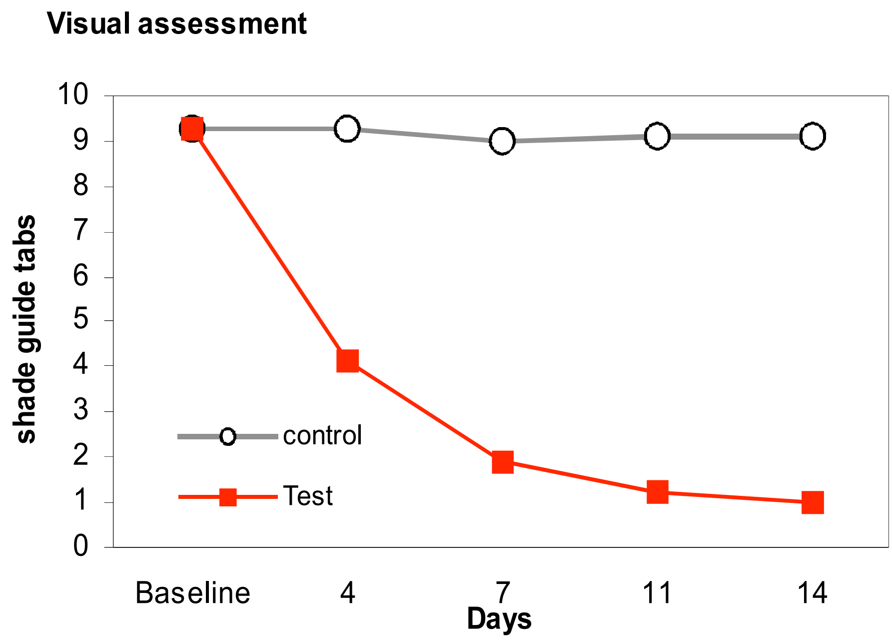

Figure 7: Change in VITA tabs as assessed visually.

	L^*	a^*	b^*	W	WIO
r^2	0.865	0.941	0.933	0.949	0.968

Table 2: Correlation coefficient (r2) between visual assessments and changes in colour coordinates obtained from the imaging system. W is the CIE whiteness index and WIO is a modified whiteness index that has been developed for use in dentistry [20].

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4 Summary

The results of the clinical trial in this study indicate that the imaging system that has been developed is effective for the clinical evaluation of tooth whiteness. Subsequent trials also support this conclusion [30]. The CIELAB values obtained using the imaging system are quite different from those that might be typically associated with white materials (the b^* value is larger than would be expected and the L^* value is low). However, such values are consistently reported by other researchers using various measurement techniques. We suggest that the white appearance of teeth is, in part, the result of cognitive factors. That is, materials with $L^* = 60$ and $b^* = 17$ would not normally appear white if viewed in a neutral context. However, the colour experienced by an observer may be influenced by expectation and possibly even memory colour when teeth are viewed in context.

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