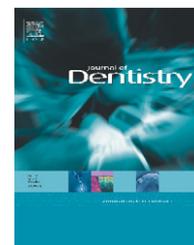


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## Comparison of the ability of different colour indices to assess changes in tooth whiteness

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### ABSTRACT

**Objectives:** The study investigates the suitability of different whiteness indices and colour parameters in assessing changes in tooth whiteness using a digital-colour imaging system. **Methods:** Forty-six male and female subjects aged 18–70 years participated in the study and were divided into two groups. The control group was given a standard “non-whitening” dentifrice (Colgate Great Regular Flavour) and the test group received whitening strips (crest white strips). The latter contained 6% hydrogen peroxide and were worn for 30 min twice daily on the six maxillary anterior teeth. Digital images of teeth were captured using a Jai 3CCD digital camera with annular LED illumination array and the data obtained was used to calculate colour parameters ( $L^*$ ,  $a^*$  and  $b^*$ ) and whiteness indices (WIC, WIO, W). Colour differences ( $\Delta L$ ,  $\Delta a$ ,  $\Delta b$  and  $\Delta E$ ) and differences in whiteness indices were obtained and were compared between the test and control groups. Reliability and repeatability of the instrument were checked by comparing the digital data to the clinical data and also by comparing data obtained from different camera views for the same tooth.

**Results:** The test group showed significant changes in the colour parameters and whiteness indices over the 2-week period. It also showed significant correlation between the digital data obtained from lateral and central camera views for the same teeth. Digital data showed a similar trend to that of clinical data. The WIO index demonstrated the strongest discrimination between the test and control groups.

**Conclusion:** The WIO index is appropriate for assessing changes in tooth whiteness. The digital imaging system is reproducible and reliable in evaluating changes in whiteness of teeth.

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## 1. Introduction

As tooth whitening has become increasingly popular and is used in general dental practices, the usage of digital photography to assess and quantify the colour changes has become

important. Digital shade systems have been designed to eliminate the subjectivity of colour analysis and to compare variations in colour parameters. The work done by Guan et al.<sup>1</sup> has shown that an imaging approach can assess the efficacy of tooth whitening products both accurately and sensitively.<sup>2</sup>

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An imaging procedure using a digital camera would allow a simple and efficient method to assess the therapeutic outcome of bleaching procedures.<sup>3</sup>

Commission Internationale De L'Eclairage (CIE) 1976 ( $L^*$ ,  $a^*$  and  $b^*$ ) colour space provides a three-dimensional representation for the perception of colour stimuli.<sup>4</sup> It is capable of representing all possible colours. This system uses three variables  $L^*$  which is the luminance which represents the difference between light ( $L^* = 100$ ) and dark ( $L^* = 0$ );  $a^*$  and  $b^*$  represents the colour values on the red-green axis and blue-yellow axis, respectively. CIELAB is one of the recommended systems for application in dentistry.<sup>5</sup> It is an international system that is present in many standards for colour measurements. Experiments were carried out to compare the changes in the colour parameters ( $\Delta L$ ,  $\Delta a^*$  and  $\Delta b^*$ ) through different tooth-whitening studies.

In fact, CIELAB was not designated to measure whiteness. Currently different whiteness indices are being used to measure tooth whiteness. WIC (CIE recommended whiteness index) is widely used in the textile, paint and plastic industries. In order for a whiteness index to be valid, it must be used on the type of material for which it is intended. Studies were carried out to optimise the coefficients of the WIC formula according to visual results and a new optimised formula was developed which is the WIO index for teeth.<sup>6</sup> A third whiteness index (W) was also included in the comparison and is based on the distance of the colour value in the colour space from a nominal white point.<sup>7</sup> This index is obtained from CIELAB values compared to the other two indices which are derived directly from the chromaticity coordinates.  $\Delta E$  (Euclidian distance) was also calculated from the  $L^*$ ,  $a^*$  and  $b^*$  values to compare the colour changes:

$$WIC = Y + 800(x_n - x) + 1700(y_n - y) \quad (1)$$

$$WIO = Y + 1075.012(x_n - x) + 145.516(y_n - y) \quad (2)$$

$$W = 100 - \sqrt{(100 - L^*)^2 + a^{*2} + b^{*2}} \quad (3)$$

$$\Delta E = \sqrt{(L_1^* - L_2^*)^2 + (a_1^* - a_2^*)^2 + (b_1^* - b_2^*)^2} \quad (4)$$

where  $(x, y)$  and  $(x_n, y_n)$  are the chromaticity coordinates of the sample and the reference white, respectively.

Many whiteness indices (WIC, WIO and W) were designated to be used only with samples whose colour coordinates were within a narrow range but that of teeth lies outside this range.<sup>8</sup> The present study was undertaken to determine the efficiency of whitening indices and colour parameters in assessing changes in tooth whiteness and to validate the imaging system. In this study reliability was checked by comparing the changes in colour parameters with the changes in clinical scores (shade guide). Repeatability was checked by correlating the mean values for whiteness indices and  $b^*$  values (subject wise) between different views of images (central, lateral left and lateral right) for the same teeth.

**Hypothesis.** WIO is the most appropriate whitening index to measure tooth whiteness.

## 2. Material and methods

All experiments were carried out in a darkened surgery to avoid ambient light falling on the tooth surface from the surrounding area. The imaging system comprised of a digital camera (Jai 3CCD) mounted in a fixed position relative to the subject. The camera provided live videos through a frame grabber card (Flashpoint 3D 4xl card, Integral Technologies Inc., IN, USA) connected to the computer. The light source was provided by an annular LED array (SCHOTT North America Inc., USA). The measurement distance of the camera was fixed at 12.5 cm from the subject. The Ring LED array with a diameter of 6 cm was fixed at the same distance as the camera from the subject (Fig. 1). Specular reflection was reduced by using a polarised filter in front of the camera.

The light source was checked and calibrated before the start of the trial by recording the spectral power distribution (SPD—plot of the radiometric quantity of as a function of wavelength) of the LED array using a Spectroradiometer Minolta CS1000 (Konica Minolta Business Technologies Inc., Tokyo, Japan) in a darkened laboratory. The measurement was done on a ceramic white calibration tile which was provided by the same company to calibrate colour measuring instru-

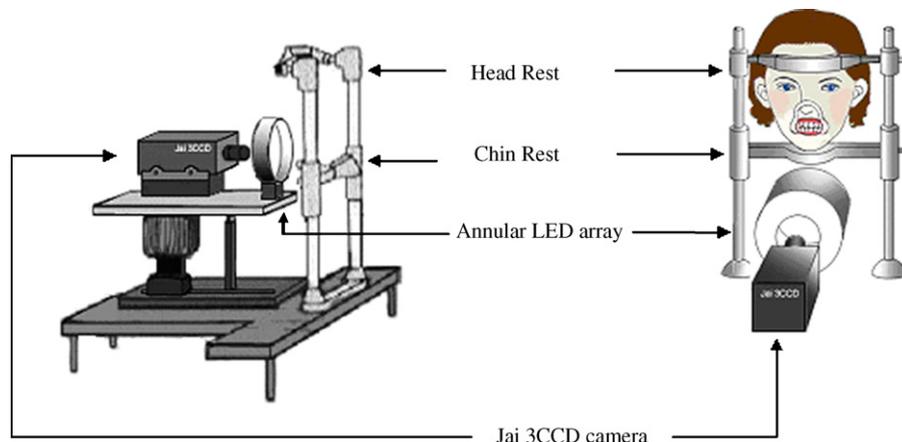


Fig. 1 – Tooth whitening camera set up.

ments. The tile was positioned at the same distance and plane as the patients' front teeth in the imaging system. The plot (SPD) was recorded which gave us a bimodal distribution with two peaks at 460 nm and 564 nm, respectively, hence the light source was considered relatively smooth providing a good coverage of visible spectrum.

Colour rendering index (CRI) is a unit of measure that defines how well colours are rendered by different illumination conditions in comparison to a standard. In order to test the ability of the LED light source to reproduce various colours when comparing with the CIE D65 (daylight), a method devised by CIE based on measuring eight sample colours was used to calculate the index. The light source was found to be 78 CRI rating, which could be considered to be not poor for colour rendering when compared to daylight illumination D65. The intensity of illumination was measured and controlled using a program written in MATLAB Version 7.0 (The MathWorks Inc., MA, USA). The voltage of the light source was adjusted according to the output RGB values of the calibration card in real time and was checked in between the imaging process.

A camera characterisation model converting linearised camera RGB  $\rightarrow$  CIE XYZ was constructed based on a linear transform, the coefficients of which were optimised based on a set of reference tooth samples (The Vita 3D Shade Guide). All other colorimetric values (such as whiteness indices and CIELAB values) were computed from the CIE XYZ values.

The study was carried out in the Department of Fixed & Removable Prosthodontics, Leeds Dental Institute, University of Leeds, United Kingdom on October 2005 and was conducted under ethical approval granted by the Leeds (East) Research Ethics Committee, Leeds, UK (Ref. 05/Q1206/96). One hundred and three patients who expressed interest in tooth whitening were selected for initial screening, all of whom had their teeth visually assessed by a dentist before the start of the trial. Candidates were screened by the dental examiner to identify those subjects who met the inclusion/exclusion criteria. Inclusion characteristics were subjects aged 18–70 who were available for the 2-week duration of the study and who had a minimum of 20 uncrowned teeth with at least 6 upper front teeth without crowns or large restorations. A minimum baseline shade of A3 on one or more of the upper front teeth was also required. The exclusion criteria were presence of orthodontics bands, partial removable dentures, advanced periodontal diseases, tumours of soft or hard tissues of the oral cavity, five or more carious lesions requiring immediate restorative treatment, allergy history, participation in another clinical study within 1 month prior to the study, recent whitening or bleaching of teeth, pregnant women and medical conditions which would compromise the subject safety or study results. Forty-six patients were finally accepted onto the study.

All the subjects accepted were randomly assigned to one of two groups (control or test) by the study nurse using a pre-prepared randomised list with stratification based on the baseline shade guide score to ensure baseline balance below and above shade tab B3. All subjects were provided with a soft-bristled adult toothbrush and a 50 ml tube of a non-whitening dentifrice (Great Regular Flavour, Colgate Palmolive, Guilford, UK) for home use. They were instructed to brush their teeth for 1 min at least twice a day (morning and evening) with their

assigned toothpaste. They were not given instructions to standardise the volume of tooth paste as the difference in the volume would have not affected the whitening results as they used a non-whitening dentifrice. Subjects assigned to the test group, which consisted of 23 patients, were asked to use a tooth-whitening system (Crest White Strips, Proctor and Gamble Inc., Cincinnati, USA) twice daily (morning and night) in accordance with the manufacturer's instructions for 14 days. This involved placing a strip coated with a gel containing 6% hydrogen peroxide on the facial surface of the six anterior maxillary teeth for 30 min. All the subjects were instructed to use only the products provided during the 2-week study period.

Teeth analysed were the maxillary right and left; central incisors, lateral incisors and canines. Blinded visual assessments and scoring were done at the baseline level, and after 7 and 14 days for both groups. This was carried out visually using shade guides (Vitapan Classical) which consisted of a range of tooth-shaped tabs of various colours that were matched to the colour of the subject's teeth. All subjects underwent an evaluation of their oral soft tissues at each of their visits to the dental facility. This examination included an evaluation of soft and hard palate, gingival mucosa, buccal mucosa, mucogingival fold areas, tongue, sublingual and submandibular areas, salivary glands, tonsillar and pharyngeal areas. The results of this evaluation were recorded on the Oral Soft Tissue and Tooth Colour Assessment Form.

Three images of the teeth were captured at each visit starting at baseline, then after 7 days and 14 days of treatment. The images were taken from central, right lateral and left lateral viewpoints. A geometry stabilising system was employed for camera movement. This facility enabled the operator to move the camera horizontally from the central position to the two lateral positions on either side. An image was captured at each position and the digital images were stored for further evaluation.

Capturing software (QLF, Inspektor Research Systems, Amsterdam, The Netherlands) was used to capture the images. RGB values of teeth were obtained by averaging camera RGB values from the buccal surface of each tooth. Mean RGB values were calculated, linearised<sup>9</sup> and converted to XYZ values by means of the characterisation model. The XYZ values were transformed into CIELAB space and whiteness indices calculated. WIO and WIC and W were computed from the formulae described earlier.

The camera and light were switched on at least an hour before the start of each day's procedure to obtain stable camera and lighting conditions. The intensity of the illumination was checked between the measurements to confirm that there was no variation between the examinations. A calibration card was used at the start and end of the image capture for each subject. The card was made by 13 grey scale patches from the Macbeth Colorchecker DC chart (GretagMacbeth LLC, NY, USA). They cover the whole range from white to black in grey scale. This card was used for the calibration of light source (white reference patch of average RGB of 248) and for the linearisation for the camera characterisation (process to build the model from RGB to XYZ). Images of the card were taken at the start of the experiment and this was used as a comparison to adjust the height of the camera assembly for subsequent visits.

**Table 1 – Comparison of mean values for  $L^*$ ,  $a^*$ ,  $b^*$ , WIC, WPG and WIO over the period of study**

Colour indices	Study group	Baseline		1 week		2 weeks		Change baseline to 1 week		Change baseline to 2 weeks	
		Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean difference	S.D. (difference)	Mean difference	S.D. (difference)
$L^*$	Test (22)	54.91	2.07	55.67	2.47	56.54	2.49	0.76	1.12	1.62	1.08
	Control (21)	55.72	2.25	54.89	2.24	55.09*	2.05	−0.83***	0.80	−0.63***	0.59
	Calibration (41)	65.44	0.20	65.19	0.17	65.35	0.14	−0.25	0.20	−0.08	0.22
$a^*$	Test (22)	8.64	1.01	8.23	1.13	7.74	1.16	−0.40	0.58	−0.89	0.57
	Control (21)	8.38	1.31	8.81	1.24	8.76**	1.24	0.43***	0.50	0.38***	0.37
	Calibration (41)	3.41	0.12	3.51	0.11	3.45	0.08	0.10	0.14	0.04	0.15
$b^*$	Test (22)	24.42	2.65	20.89	1.90	19.93	1.93	−3.53	1.37	−4.49	1.67
	Control (21)	24.68	2.29	23.57***	1.97	23.82***	2.16	−1.11***	0.52	−0.85***	0.34
	Calibration (41)	1.90	0.13	1.17	0.28	1.46	0.29	−0.73	0.28	−0.44	0.28
WIC	Test (22)	−142.29	15.78	−117.59	12.56	−109.20	13.30	24.7	9.51	33.09	12.10
	Control (21)	−141.87	17.95	−137.09***	15.58	−138.14***	16.63	4.78***	3.87	3.73***	2.37
W	Test (22)	47.87	1.89	50.22	2.35	51.49	2.47	2.35	1.39	3.61	1.65
	Control (21)	48.53	2.80	48.27*	2.61	48.34***	2.56	−0.25***	0.82	−0.19***	0.55
WIO	Test (22)	−77.88	9.22	−63.99	9.13	−57.93	9.69	13.89	6.23	19.94	7.72
	Control (21)	−76.43	13.04	−75.84***	11.77	−76.08***	12.22	0.60***	3.30	0.36***	2.11

\*0.05, \*\*0.01, \*\*\*0.001.

Forty-three subjects completed the study, 22 in the test group and 21 in the control group. One subject failed to attend the 7- and 14-day visits from the test group due to ill-health and was withdrawn from the study. Two subjects failed to attend the 14-day visit from the control group due to the same reason and were withdrawn from the study. Data for colour analysis and comparison was available for all subjects who completed the study. The data obtained was analysed statistically using SPSS Version 12.0. The data obtained for each tooth was aggregated, first tooth-wise (central incisor, lateral incisor and canine) and then values for the same tooth for different views were amalgamated to obtain subject-wise scores. An independent sample t-test was used to compare the test and control groups; Spearman correlation coefficients were obtained to compare clinical to digital data. Comparison of digital data between the two viewpoints (central and lateral) was done using interclass correlation coefficients.

### 3. Results

Mean and standard deviations of the colour parameters ( $L^*$ ,  $a^*$  and  $b^*$ ) and whiteness indices (WIC, WIO and  $W$ ) were calculated for each time period (Table 1) and an independent sample t-test was carried out. This was done to compare the mean values between the control and test groups for each period and also between the changes in the values from baseline to each examination period.

$L^*$  values showed significant difference in its mean ( $p < 0.05$ ) in the second week. It also showed significant difference ( $p < 0.001$ ) for the change in its measurements in the first and second weeks between the test and control groups. The difference in the mean  $a^*$  and  $b^*$  values from baseline to the first and second weeks were compared between the two groups and showed significant difference ( $p < 0.001$ ). The whiteness indices WIC, WIO and  $W$  showed significant differences in their mean values between the control and test group for each particular period starting from baseline. As expected there was only a little variation in the CIELAB values across the period for the calibration card.

CIELAB colour differences ( $\Delta E$ ) were calculated to evaluate the amount of change that occurred for the test and control group after 7 and 14 days, respectively. The  $\Delta E$  value for the test group was 4.95 units over the period of study (Table 2). The control group showed a net  $\Delta E$  value of 1.27 units after 14 days. In the first 7 days the control group showed a mean  $\Delta E$  value of 1.65 which was reduced by 0.38 units in the last 7 days.

To assess the changes in the values, a graph (Fig. 2) was plotted with the changes in  $b^*$  values (2 weeks) against its

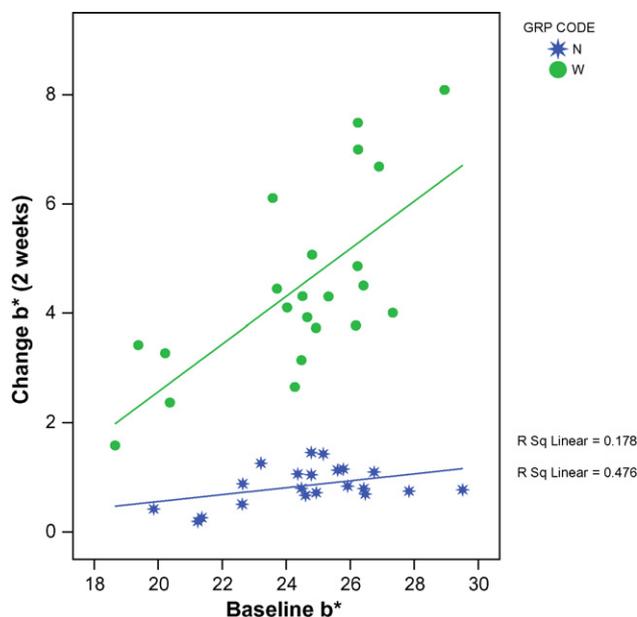


Fig. 2 – Graph plotted with baseline  $b^*$  values against the change in its value over 2-week period (control (N) and test group (W)).

corresponding baseline values. The graph showed higher change for the test group compared to the control group. The change in the  $b^*$  values increased with its corresponding baseline  $b^*$  values; hence, subjects with higher  $b^*$  values tend to show a larger change.

The t-statistics for the changes in each index over the study period were calculated using an independent sample t-test.

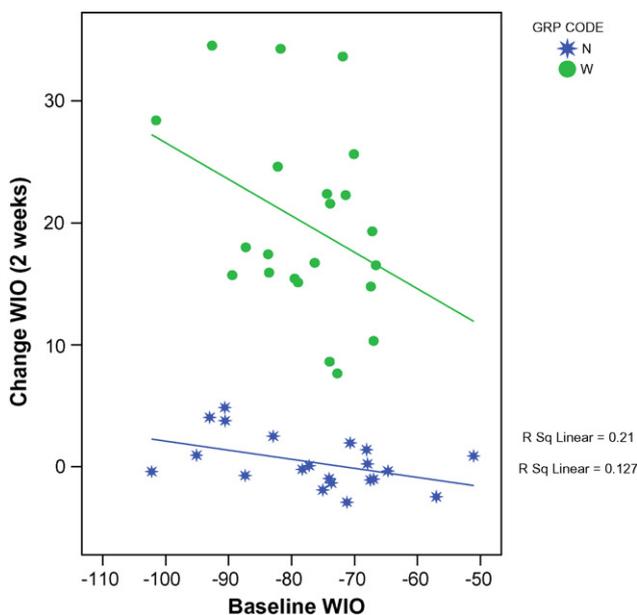


Fig. 3 – Graph plotted with WIO baseline values to the changes in its corresponding values over the 2-week period (control (N) and test group (W)).

Table 2 –  $\Delta E$  values for both test and control group (subject wise) from baseline to 7 and 14 days period

	Colour difference	7 days	14 days
Test	Mean ( $\Delta E$ )	3.83	4.95
	Standard deviation ( $\Delta E$ )	1.40	1.85
Control	Mean ( $\Delta E$ )	1.65	1.27
	Standard deviation ( $\Delta E$ )	0.72	0.48

**Table 3 – Showing correlation between the mean changes in clinical scores to that of changes in the colour parameters and whiteness indices**

Number of subjects	Values	Duration	Spearman correlation coefficient
43	$\Delta L^*$	2 weeks	0.581**
43	$\Delta a^*$	2 weeks	-0.633**
43	$\Delta b^*$	2 weeks	-0.654**
43	$\Delta WIC$	2 weeks	0.646**
43	$\Delta WPG$	2 weeks	0.605**
43	$\Delta WIO$	2 weeks	0.615**
43	$\Delta E$	2 weeks	0.670**

\*0.05, \*\*0.01, \*\*\*0.001.

$\Delta WIO$  showed the highest value, followed by  $WIC$  and  $WPG$  as shown below:

$$\Delta WIO (11.21) > \Delta WIC (10.91) > \Delta WPG (10.03) > \Delta b^* (9.78) > \Delta E (8.84)$$

To further investigate the  $WIO$  index, a graph (Fig. 3) was plotted with its baseline value against corresponding change over the study period. The graph confirmed that the change in the test group was higher when compared to the control group. The control group had its values scattered around 0 indicating less change. The index also showed good separation of the scatter points between the test and control group.

The Spearman correlation test was carried out to assess the variation of clinical scores with the digital data. The results shown in Table 3 indicate significant correlation ( $p < 0.01$ ) for all the subjects between the clinical scores and digital data. Correlation coefficient was maximum for  $\Delta E$  value (0.670) followed by  $\Delta b^*$  (-0.654) and  $\Delta WIC$  (0.646).

The change in the values (Table 4) showed a high correlation coefficient (interclass) between the image views (lateral and central) for all the measurements.  $WIC$  (0.977)

showed the highest correlation among the whiteness indices followed by  $WIO$  and  $W$ . The correlations for all the indices were significant at  $p < 0.001$ .

#### 4. Discussion

$L^*$  and  $a^*$  values showed statistically significant changes by the second week of the study for the test group.  $CIELAB b^*$  showed significant change by the first week of treatment for the test group. Whiteness indices showed statistically significant  $p$  values for the test group compared to the control group from the first week which indicated that the whitening product increased the whiteness of the teeth. A decrease of 3.35 units for the  $b^*$  values was observed in the whitening strips compared to 1.67 for the tray where the study was intended to compare 14% hydrogen peroxide whitening strips to marketed 9.5% hydrogen peroxide custom tray based system for a period of 21 days.<sup>10</sup> Clinical trial carried out by Gerlach et al. on 43 subjects, observed a significant reduction of yellowness with a reduction in the  $b^*$  value of 1.83 units using a 5% carbamide peroxide professional custom tray system in a period of 15 days.<sup>11</sup> Another study on 20 healthy adults randomised to two groups which was carried out by Gerlach et al. comparing 6.0% hydrogen peroxide strip-based bleaching system to a combination system (10% carbamide peroxide gel in a stock tray along with an anti-cavity whitening dentifrice and after-bleaching whitening mouth-rinse) with the same duration as the present study obtained a reduction in  $b^*$  value of 2.23 for the whitening strips and 0.97 for the tray system.<sup>12</sup>  $\Delta b^*$  values observed in our study for the crest white strips was higher compared to that obtained by the tray system in the aforementioned studies.

A study carried out by Sagel et al.<sup>13</sup> using a similar kind of tooth-whitening system (Crest White Strips) with 6.5%

**Table 4 – Showing correlation between the change (mean) in values of the lateral and central image views for each study period**

Number of subjects	View	Values	Duration	Interclass correlation coefficient
43	Central	$b^*$	1 week	0.971***
43	Lateral			
43	Central	$b^*$	2 weeks	0.983***
43	Lateral			
43	Central	$WIC$	1 week	0.966***
43	Lateral			
43	Central	$WIC$	2 weeks	0.977***
43	Lateral			
43	Central	$WPG$	1 week	0.955***
43	Lateral			
43	Central	$WPG$	2 weeks	0.956***
43	Lateral			
43	Central	$WIO$	1 week	0.960***
43	Lateral			
43	Central	$WIO$	2 weeks	0.966***
43	Lateral			

\*0.05, \*\*0.01, \*\*\*0.001.

hydrogen peroxide on 11 patients reported significant changes in the colour parameters. Their study evaluated only the  $\Delta E$  and  $\Delta b^*$  values compared to this study which considered the whiteness indices as well. They obtained a lower  $\Delta E$  (2.8) and  $\Delta b^*$  (-2.3) compared to 4.95 and -4.49 in the current study. The reason for the increase in the values in our study could be that this study included canines which have higher  $b^*$  baselines and show a larger change due to whitening. Similar results have been reported in a review article by Gerlach and Zhou where mean  $\Delta b^*$  of -2.4 was observed for tooth colour using whitening strips for 30 min twice daily for a period of 2 weeks.<sup>14</sup>

The CIELAB values for the control group were fairly constant throughout the period of the trial with negligible variation compared to the significant changes in the test group. The same trend was seen for the whiteness indices. Consistency in the CIELAB values and whiteness indices for the control group during the trial period confirmed the stability of the instrument. The calibration and stability of the instrument is crucial in obtaining accurate and reliable results as even the smallest instrument errors can cause drift in the values obtained of the order of  $\Delta E$  of 1.<sup>15</sup> CIELAB values of the calibration card were compared to ascertain if there were any variations in the values.

In vitro tooth-whitening studies were done using 1% hydrogen peroxide using reflectance spectrometry and the study indicated that the reduction of  $b^*$  values occurred more rapidly and to a greater extent than the  $L^*$  factor.<sup>16</sup> The study concluded that the  $b^*$  component is a more important indicator of tooth whitening in bleaching. The whitening study reported by Goodson et al.<sup>17</sup> reaffirms that whitening reduces yellowness ( $b^*$ ) more consistently than they increase  $L^*$ . They used a colorimeter to obtain the CIELAB values from 43 subjects where peroxide and light were used to bleach the teeth. As  $b^*$  value is one of the component of CIELAB and a more important vector component in the whiteness change, the variation in its value was plotted on a scatter graph. Fig. 2 indicated marked changes in the  $b^*$  values for the test group compared to the control group. Teeth with higher baseline  $b^*$  values had a more pronounced change in the graph. Hence, the darker or more yellower the tooth the greater the potential change in its  $b^*$  values due to whitening. Even though changes in  $b^*$  is an important indicator in whiteness, none of the component vectors of CIELAB could be considered in isolation to measure tooth whiteness.

The fact that the control group gave a  $\Delta E$  value more than 1 for both the first and second weeks should be taken into consideration even though in dentistry  $\Delta E$  less than 2.75 could be considered as a clinically acceptable colour difference for teeth.<sup>18</sup> The difference can be attributed to instrument noise during the 2-week period or can be due to increased oral hygiene by the patients or a combination of both. During the trial period subjects tend to be more careful as they are aware that they are in a whitening study. The  $\Delta E$  value of the control group should be considered while assessing the values of the test group as the same factors would have affected the  $\Delta E$  value of the test group.  $\Delta E$  measures the variability in the colour not necessarily the changes in whiteness.

Shade guides should remain a critical element in assessing the whitening in any tooth bleaching study.<sup>19</sup> The clinical scoring using a shade guide was compared with the digital

data in this study. Significant  $p$  values (Spearman correlation) for all the parameters indicated a fairly good correlation between the clinical score and digital data. The correlation coefficients had values close to each other suggesting that the changes in the colour parameters and indices obtained from digital imaging were similar to each other when compared to clinical scores.

The measurement of tooth colour, particularly in developing an effective method to measure the ability of a system intended to change the tooth whiteness, remains a challenge.<sup>20</sup> Li has also emphasised the need to develop and improve the instrument and technique for quantitative measurement of tooth colour and interpretation of data for evaluating tooth colour change. Comparing the  $t$ -statistics over the period of study between the whiteness indices indicated maximum value for  $\Delta WIO$  values followed by  $\Delta WIC$  and  $\Delta W$ . It was therefore concluded that  $WIO$  is the most appropriate index in measuring differences in tooth whiteness. Data from central and lateral photographic views of the same tooth on comparison showed significant correlation indicating a stable system and reproducible results.

## 5. Conclusion

The darker and yellower the teeth the more pronounced were the whitening changes observed in the present study. All indices ( $WIC$ ,  $WIO$  and  $W$ ),  $b^*$  and  $\Delta E$  values showed a similar trend and correlation to that of clinical scores and in between the different viewpoints (central and lateral), suggesting that they are equally good in determining the colour change in a whitening study.  $WIO$  was concluded as a more appropriate index on the basis of  $t$ -statistics to measure difference in tooth whiteness among the whiteness indices. Fairly consistent calibration values, highly correlated colour parameters between the lateral and central viewpoints and less variation in the control group indicate that the results are repeatable and reliable and the digital system is robust in evaluating the whitening change in tooth bleaching.

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