Validation of a Tooth-Imaging System in Tooth-Whitening Trials

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Abstract

This study investigates the validation of a tooth imaging system in assessing changes in tooth whiteness in clinical dental trials. Sixteen male and female subjects aged between 18-70 years participated in the study and were divided into two groups. The control group was given a non-whitening toothpaste, whereas the test group used a tooth-whitening system for 14 days. Five Images were taken at the beginning of the trial (baseline), 4^{th}, 7^{th}, 11^{th} and 14^{th} day of the treatment. Camera RGB values were transformed to CIELAB space, and colour differences and three whiteness indices were calculated. The test group showed obvious changes in colour coordinates and whiteness indices over the two week period, while the control group kept stable in tooth colour. At the meantime of image capture, visual assessments by a dentist were done in a typical clinical surgery. The comparison result between the camera measurements and visual assessments also proved the validation of the tooth-imaging system for measuring tooth-whiteness.

Introduction

As tooth whitening has become a popular and routine dental procedure that can even be carried out by the consumer at home, the measurement of tooth colour, especially for the evaluation of the efficacy of the tooth-whitening products, is becoming increasingly important. However, it is also challenging. One of the methods of assessing whitening results is digital photography. Photography has been used for many years for different purposes in dentistry. It provides the dentist with information about teeth such as surface texture, shape and colour distribution. The increasing interest in tooth-whitening raises the need for digital photography to record and assess the colour of teeth in clinical whitening trials.[1-3]

This paper describes a double-blind clinical study designed to investigate the ability of an imaging system to measure the efficacy of a tooth-whitening product (Colgate Platinum Overnight) on a group of 16 patients ranging in age from 18 to 50. The imaging system has been developed collaboratively by Leeds University and the Colgate-Palmolive company. The use of an imaging system to assess the efficacy of tooth-whitening products relies upon two things: (i) precise, and preferably accurate, colorimetric measurements; (ii) an appropriate whiteness scale or index. Previous work by the authors has validated the performance of the imaging system in the laboratory[4] and has developed and validated an optimized whiteness index (WIO) based upon the structure of the CIE whiteness index[5,6]. In this study, the performance of the imaging system is assessed under the conditions of a clinical whitening trial.

Experimental

All experiments were carried out in a darkened surgery in the Dental Institute at the University of Leeds. Figure 1 shows the schematic of the tooth-imaging system with the light baffle removed for clarity.

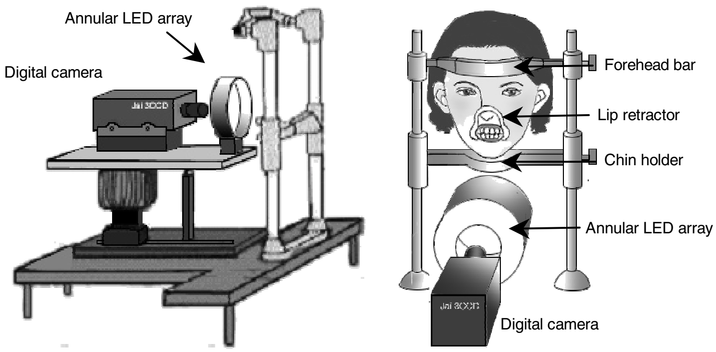

Figure 1: *Schematic of the imaging system with the light baffle removed for clarity.*

The imaging system comprised of a digital camera (Jai 3CCD) mounted in a fixed position relative to the subject. The camera provides live videos through a frame-grabber card (Flashpoint 3D 4xl card, Integral Technologies, Inc.) connected to a computer. The light source was provided by an annular LED array (Schott North America, Inc USA) within a light baffle to reduce the intrusion of ambient lighting. The measurement distance of the camera was fixed at 12.5 cm from the subject. A polarising lens was situated in front of camera lens to minimize any specular reflection from the teeth. The intensity of the light source was controlled with the aid of a program written in MATLAB to ensure that it was stable over the trials. A camera characterization model converting linearized RGB→XYZ was constructed based upon linear transform, the coefficients of which were optimized based on a set of reference porcelain teeth samples (the Vita 3D shade guide). The repeatability of the system was about 0.8 ΔE^*_{ab} units which was considered to be acceptable for the whitening trials because colour changes in teeth less than 1 ΔE^*_{ab} unit can hardly be distinguished visually.

Candidate patients were screened by a dentist to identify those subjects who met the inclusion and exclusion criteria. Inclusion characteristics were subjects aged 18-70 who had a minimum of 20 uncrowned teeth with one or more of the upper front teeth were about shade of A3 or darker on the VITA classical shade guide scale[7]. The exclusion criteria were presence of orthodontics bands, partial removable dentures, advanced periodontal disease, 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 one month prior to the study, recent whitening or bleaching of teeth, pregnant women an medical conditions which would compromise the subject safety or study results. Sixteen patients were finally accepted onto the study and were separated into a control group and a test group. The test group (8 patients) used a tray-based whitening system (Colgate Platinum Overnight[8]) during the trial for 14 days. This tray-based whitening product contains 10% carbamide peroxide and has an established whitening effect, whereas the control group (8 patients) used non-whitening toothpaste.

QLF software (Inspektor Research Systems, The Netherlands), which is widely used in fluorescence image capturing in dentistry, was applied to align the positions of patients' heads during trials. The intensity of the LED light source was checked between measurements to confirm that it remained stable between the examinations. A greyscale card was captured at the start and the end for imaging each subject. It was used as a height record of the camera assembly for subsequent visits, since patients have different heights of chin which will influence the teeth-position in the captured images.

A total of five images were taken for each subject. The first image was taken at the beginning of the trial (baseline) and subsequent images were taken after 4 days, 7 days, 11 days and 14 days of treatment. RGB values of teeth were obtained by averaging camera RGB values from a substantial area from each of the two central upper (maxillary) incisors (since teeth are not perfectly spatially uniform in colour). Mean RGB values were calculated and then linearized and converted into XYZ values by means of the characterization model. The XYZ values were transformed into CIELAB space, and three whiteness indices—CIE Whiteness Index (WIC), a specially optimized whiteness formula (WIO)[5,6] and W—were used to quantify the changes in tooth whiteness.

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

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

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

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

In the meantime of the trial, visual assessments by a dentist in Leeds Dental Institute were conducted to verify the colour changes detected by the imaging system. Teeth of the patients were measured using the Vita classical shade guide tab system (Figure 2) at each time of patients' visits.

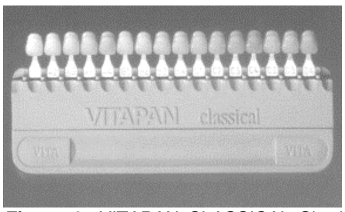

***Figure 2:** VITAPAN CLASSICAL Shade Guide, a set of porcelain teeth that is used in the dental community for shade assessment purposes. It consists of 16 teeth with a simpler arrangement in a general trend from lightest to darkest when moving from left to right, though with some reversals in Lightness in the standard order.*

Results

Mean CIELAB colour coordinates and whiteness indices were computed for each patient for each of the four five images taken in the trial. Colour changes between the baseline and each following visit were summarized in Table 1.

It is evident that there was little colour change for the control group whereas the teeth of the test group became lighter and less chromatic as the trial progressed. Form Table 1 and Figure 3, the b* values especially had a dramatic decrease (about 3 units) for the test group comparing with L* and a*, which could indicate that the teeth became less yellow during the treatment. This result was consistent with the general feeling of teeth whitening process that teeth become lighter and less yellow after bleaching.

Table 1: Comparison of changes in CIELAB space and whiteness indices

Colour indices	Study group	4^{th} vs. baseline	7^{th} vs. baseline	11^{th} vs. baseline	14^{th} vs. baseline
ΔL*	Control	0.188	0.338	0.099	0.226
	Test	0.745	1.491	1.530	1.066
Δa*	Control	0.107	0.010	0.137	0.029
	Test	-0.451	-0.662	-0.712	-0.807
Δb*	Control	-0.141	0.860	0.008	-0.111
	Test	-2.896	-2.902	-3.573	-3.350
ΔE^*_{ab}	Control	0.26	0.92	0.17	0.25
	Test	3.02	3.33	3.95	3.61
ΔWIC	Control	1.430	-4.625	0.276	1.293
	Test	20.399	22.119	26.555	24.012
ΔW	Control	0.208	-0.025	0.067	0.251
	Test	1.793	2.516	2.772	2.289
ΔWIO	Control	0.588	-2.022	-0.092	0.756
	Test	11.589	13.467	15.768	14.408

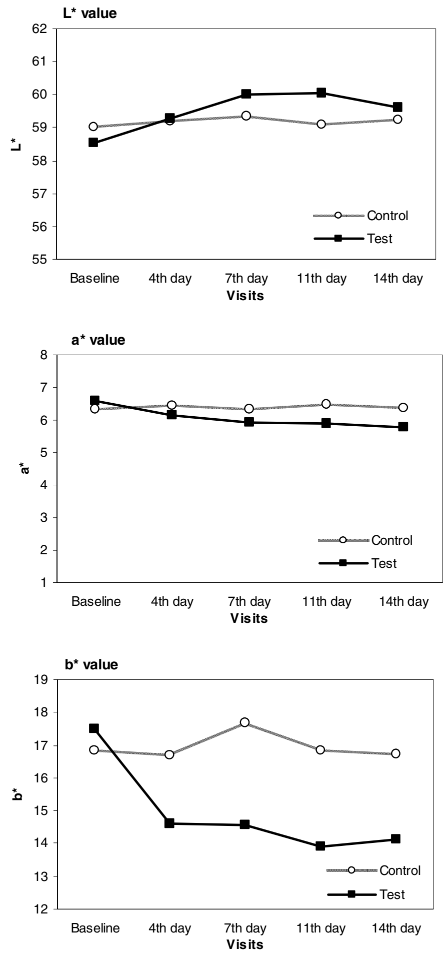

***Figure 3:** Changes in CIELAB space for control and test groups in the tooth-whitening trials*

We note, however, that there were small differences between the absolute colour measurements for the two groups. In order to check whether the baseline colours were really different or not, an unpaired t-test was employed to test the difference in means of the two groups. From the statistic analysis, it was confirmed that there was no statistically significant difference between the two groups in baseline colour (p values for L*, a* and b* were 0.69, 0.61, and 0.31 respectively).

The ΔE^*_{ab} data confirmed that the main colour changes occurred in the first few days of applying the whitening product and that at the end of the trial a mean colour difference of around 4 ΔE^*_{ab} units was measured in the test group. The variation in the control group was less than 1 ΔE^*_{ab} unit over the trials which, considering the precision error of the system ($0.8\Delta E^*_{ab}$ unit[4]), was of the expected order of magnitude. Note that there was a slight reversal in whiteness between the 14th-day's and 11th-day's data for the test group. This fact may be caused by the system repeatability error as well. Small colour changes below this level ($0.8\Delta E^*_{ab}$ unit) may not be detected by the system.

From the data of the three whiteness indices, the trends of increase for the test group are obvious, though the amount of changes were in different scales. Positive changes in the WIO are considered to indicate an increase in whiteness and such changes were observed for the test group at all stages in the trial.

It was found these whiteness indices change in different degrees when colour changes in a same amount. In order to analysis the stability/sensitivity of the whiteness indices to tooth colour changes, an additional test was conducted. An average tooth colour was chosen from the teeth-imaging trial as a test sample (L*= 59.00, a*=6.33, b*=16.84). Generally, the most common colour change in tooth-whitening study is becoming lighter and less colourful. Take increase 1% as an example, the Y value of the test colour was increased by 1% and x and y values were decreased by 1%, the sequent amount of increase in whiteness indices values were calculated and plotted in Figure 4.

It is believed that an index responds to the stimulus change too sensitively or too consistently may be not a good. A too sensitive index may take noise as useful signal, whereas a too steady system may react too indistinctly to signal changes. From the sensitivity test, it was found that the WIC has the biggest increase about 9 units, WIO has an amount of change about 5 units, W was much less sensitive since the change was below 1 unit.

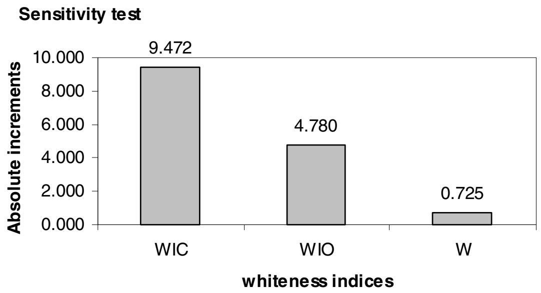

Figure 4: Absolute increments of whiteness indices when increasing Y by 1%, decreasing x and y by 1%

In the meantime of the imaging trial, blinded visual assessments and scoring were done for both groups. At the same days of image capture, colours of the patients' teeth were matched to the Vita classical shade guide tab system. The mean reduction in shade guide scores was 8.25 shade guide tabs for patients in the test group after the 14 days treatment, compared to nearly no shade change for those in the control group.

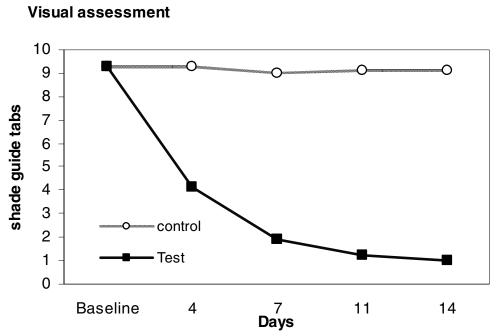

Figure 4: The colour changes in Vita shade guides in the visual assessment Differences in WIO for control and test groups in the tooth-whitening trials

In order to check the agreement between the imaging system measurements and visual assessments on teeth colours, the correlation coefficients between the camera measuring results (L*, a* b* and three whiteness indices) and the visual scoring were computed and listed in Table 2 for the test group. It was found that for all these colour coordinates and whiteness indices highly correlated to the visual evaluation results, where WIO had a slightly higher value of the correlation coefficient.

able 2: Pearson correlation coefficients between the camera measurements and the visual assessments

	L*	a*	b*	WIC	W	WIO
Visual	0.865	0.941	0.933	0.949	0.957	0.968

Conclusion

In conclusion, after the first clinical trial, the tooth-imaging system was considered to be valid and sensitive to measure the effect of tooth-whitening products. These findings have implications in the use of digital camera in the assessment of colours related to dental aesthetics, particularly tooth colour. In addition to evaluate efficacy of various tooth-whitening products in the short future, this system could be modified for further applications like measuring changes in gingival (gum) colours over time which would have applications for another area of dentistry.

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