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A Review of Methods Used for Analysing Colour Data in Dental Studies Evaluating Colour Match of Restorative Materials

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Abstract

Objectives: To review the colour data, and statistical tests used to analyse these colour data in studies evaluating colour match of restorative materials in dental research.

Data/Sources: An internet search was undertaken in March 2010 using the Pub Med database for papers published in the last five years using the following keywords: (colour OR shade), (porcelain), (match OR matching OR difference OR differences).

Study selection: Dental studies were selected using the following inclusion criteria: all studies investigated the colour change or colour match of all-ceramic materials, used colour-measuring devices to measure colours, and used CIE LAB colour space to express colours. The following exclusion criteria were applied: case studies, over-time clinical evaluation of porcelain materials, and studies investigating all-ceramic along with metal-ceramic materials. Nineteen included studies were reviewed.

Conclusion: Analysing the ΔE* and/or ΔL*, Δa* and Δb* values calculated between experimental samples and baseline can be the appropriate colour variable to be investigated in dental colour research. However, providing a consistent baseline or where no baseline is used, other colour variables can also be investigated. Presenting ΔE* values in means ± SD or CI is very useful to compare with clinically acceptable thresholds.

***Keywords:** Colour OR shade; Porcelain; Match OR matching OR difference OR differences*

Introduction

Colour difference data is important in dental research, to estimate whether the changes in the outcome colour of restorative materials or the colour difference between teeth and aesthetic restorations are perceptible by the human observer.

The colour difference ΔE* magnitude between two specimens whose colour is expressed in CIEL*, a*, and b* (CIELAB colour space) is calculated using the following equation [1]:

$\Delta E*_{12} = \sqrt{(L_1 * - L_2 *)^2 + (a_1 * - a_2 *)^2 + (b_1 * - b_2 *)^2}$. The L* colour coordinate ranges from 0 to 100 and describes brightness on the y axis; the a* colour coordinate ranges from −90 to 70 and describes greenness on the positive x axis and redness on the negative; the b* colour coordinate ranges from −80 to 100 and describes yellowness on positive z axis and blueness on negative [2].

The colour difference (ΔE*) and colour coordinates L*, a*, and b* determined by using colour-measuring instruments have been widely used in dental studies. For instance, to illustrate if there is any difference between a colour measured by a colorimeter and that determined by human observers in metal-ceramic restorations [3], and to demonstrate the influence of varied high-palladium alloys on the overall colour of opaque porcelain [4]. Additionally, ΔE* has been applied in other fields, for example, to investigate the use of ozone technology in decolouration and recycling of acid dye effluents for dyeing of silk fabric [5].

The use of colour difference data should parallel to a high degree to the human detection of colour changes. It has previously been indicated that colour changes more than 1 ΔE* unit are visually perceptible by 50% of human subjects [6]. However, in clinical situations, such small changes in colour may be acceptable, as 5.5 ΔE* units have been suggested as a threshold for colour match or mismatch in clinical environments [7]. However, different ΔE* values have been suggested by different researchers to express the borderline for clinical acceptance of colour change: 6.8 ΔE* units [8]; 3.3 ΔE* units [6]; 2.72 ΔE* units [9] and 2 ΔE* units [10].

The aim of this paper was to review the colour data, and assess methods of statistical analysis used in studies evaluating colour match of restorative materials in dental research.

Methods

Literature search

For the identification of dental studies included or considered for this review, an internet search was undertaken in March 2010 using the Pub Med database. The following keywords were used for the search: (colour OR shade), (porcelain), (match OR matching OR difference OR differences). This search was limited to articles from dental journals, English language, and published in the last five years. Ninety-eight studies were found as a result of this search.

No additional hand searching of journals was undertaken.

Inclusion and exclusion criteria

Dental studies were selected using the following inclusion criteria: all studies investigated the colour change or colour match of all-ceramic materials, used colour-measuring devices to measure colours, and used CIE LAB colour space to express colours.

The following exclusion criteria were applied: case studies considering only one case or sample; over-time clinical evaluation of porcelain materials which emphasised the physical functional durability rather than colour durability of these porcelain materials; and studies investigating all-ceramic along with metal-ceramic materials which investigated the colour of these materials as a secondary part of the study.

Evaluation of papers

Nineteen studies were finally included in this review [11-29]. All included studies were evaluated to identify the following: the outcome colour variables investigated, statistical methods used to analyse these variables, and the clinically acceptable thresholds used to compare colour difference values.

Subsequently, in an attempt to assess the possible effects of statistically investigating different colour variables on the outcome findings, statistical analyses were applied on three different colour variables obtained from an example data set from a study investigating the effect of resin cement on the final colour of porcelain veneers. In this study, the colour difference between three different shades (white, dark and neutral) of Calibra resin cement (Dentsply International) has been evaluated. Vitadur Alpha porcelain veneers of shade 1M1 VM7 (Vita, Zahnfabrik, Bad Sackigen, Germany) were applied to bovine teeth using the Aquagel (Aquagel is a commercial water gel: Aquagel® - Adams Healthcare, UK) as a baseline and the colour measured, and each group of veneers were then cemented with one shade of resin cement (detailed methods were explained in a previous paper [30]).

Results

The colour variables, method of analysis, and perceptible thresholds used in each study are listed in Table 1.

	Outcome colour variables investigated					
	Between experimental groups and baseline		Between experimental groups and a target		Absolute colour coordinates of experimental groups	Acceptability threshold used
Author	ΔE*	ΔL*, Δa*, Δb*	ΔE*	ΔL*, Δa*, Δb*	L*, a*, b*	ΔE*(units)
Saygili, 2006	Y	Y				3.3
Shimada, 2006	Y	Y				2
Samra, 2008	Y	Y				3.3
Chang, 2009	Y					2
Karaagaclioglu, 2008	Y					3.7
Charisis, 2006			Y	Y		3.7
Chu, 2007			Y			
Li, 2009			Y			3.7
Sailer, 2007			Y	Y (ΔL* only)		3.7
Yu, 2009			Y	Y (ΔL* only)		3.7
Kautayas, 2008			Y	Y		3.7
Shereen, 2006			Y		Y	2.6
Uludge, 2007	Y				Y	1 (perceptible)
Lee, 2007			Y		Y	3.7
Kucukesmen, 2008			Y		Y	2.5
Celik, 2008					Y	3.7
Volpato, 2009			Y	Y	Y	3.7
Ozturk, 2008					Y	3.7
Terzioglu, 2009	Y				Y	3.7

Table 1: *Summary of outcome variables and acceptability thresholds used in the studies included in the review.*

In all reviewed studies, the differences between and within experimental groups were assessed for statistical significance using analysis of variance (one-way or two-way ANOVA test) with at least one of the post-hoc pairwise tests for multiple comparisons on the following colour variables: colour difference ΔE* and/or ΔL*, Δa*and Δb* values calculated between experimental groups and their baselines [seven studies 11-15,23,29], colour difference ΔE* and/or ΔL*, Δa*and Δb* values calculated between experimental groups and a target (reference) [ten studies 16-22,24,25,27], and absolute colour coordinates L*, a*and b* values of each experimental group (As a spectrophotometer measures the colour of a sample, it express colour in three absolute colour coordinates L*, a* and b* which means primary colour coordinates) [eight studies 22-29].

The colour evaluation was based on the CIE L*, a* and b* uniform colour space using colourimeters in five studies [12,15,17,23,25] and spectrophotometers in the other fourteen studies. Materials of similar translucency were evaluated in the reviewed studies: all-ceramic materials were evaluated in all reviewed studies, besides resin composites in two of the reviewed studies [13,25].

Moreover, in most of the studies (eighteen), ΔE* values were assessed for clinical significance by comparing the ΔE* values to the perceptibility and acceptability thresholds of colour difference in clinical situations. However, different acceptability thresholds were used in different studies.

The potential effect of outcome variable choice is illustrated using an example data set comparing the final colours of porcelain veneers using three shades of resin cement. Table 2 shows the p-values from Tukey post-hoc pairwise tests between shades using the outcome variables identified from the review studies (ΔE*, ΔL*, Δa*, Δb* between final colour and individual baseline, ΔE*, ΔL*, Δa*, Δb* between final colour and target shade, and absolute L*, a*, b* co-ordinates). The table shows that when using ΔE* between final colour and target shade, significant differences was found in colour change between the neutral shade and both white and dark shades, whereas no significant differences were found using ΔE* between final colour and individual baseline.

ΔE*		between each shade and its baseline				between each shade and 1M1 shade tab				Absolute colour co-ordinates		
		ΔL*	Δa*	Δb*	ΔE*	ΔL*	Δa*	Δb*	L*	a*	b*	
Calibra	white dark	0.125	0.557	0.051	0.219	0.280	0.494	0.141	0.508	0.511	0.169	0.51
	white neutral	0.587	0.003#	0.995	0.009#	0.019#	0.216	0.304	0.010#	0.237	0.35	0.011#
	dark neutral	0.563	0.037#	0.041#	< 0.001#	< 0.001#	0.021#	0.892	0.001#	0.025#	0.893	0.001#

Table 2: *p-values from Tukey post-hoc pairwise tests for comparison of cement shades in an example data set, using the various outcome variables identified in the review studies.*

 # mean difference is significant at the 0.05 level

Using the separate co-ordinate variables showed significant differences in the L and b directions whichever outcome variable was used, but for the a co-ordinate, the only significant difference was found using Δa* between final colour and individual baseline.

Clinically acceptable (ΔE* < 5.5 units which is the value used in the example study about effects of resin cement on the colour of porcelain veneers) colour differences were found between all shades of Calibra resin cement and their baseline (ΔE* (95% CI) = 2.35 (1.76 - 2.94), 3.20 (2.66 - 3.74) and 2.77 (2.16 - 3.38) for white, dark and neutral shades respectively). However, these mean colour differences lie above the clinically acceptable threshold of 2 ΔE* units used in Chang's study [14], with the dark and neutral shades statistically significantly higher.

Discussion

In the dental studies reviewed, different colour outcome variables were investigated, including ΔE* values and/or ΔL*, Δa*, and Δb* values calculated between experimental groups and their baseline, ΔE* and/or ΔL*, Δa*, and Δb* values calculated between experimental groups and a target, and absolute colour coordinates L*, a* and b* of each experimental group. These variables were analysed using analysis of variance ANOVA with a post hoc test for multiple comparisons. ΔE* values and/or ΔL*, Δa*, and Δb* values were assessed for clinical significance by presenting them using means and confidence intervals, and comparing them to an acceptability threshold of colour difference. These results informed the different colour variables chosen for investigation in the example data set of the study evaluating the colour changes of porcelain veneer restorations cemented using different shades of Calibra resin cement.

Colour measurement of dental materials is influenced by many variables including the colour-measuring instruments, measuring geometries, translucency of the materials, layered samples, background colours and edge loss effect which has considerable influence on colour measurement especially of translucent samples. It is important to bear these variables into mind when colour measurements of dental materials are compared, especially when comparing colour measurements between different studies and different materials. However, this study focuses on the statistical tests applied to colour variables in different dental colour studies, and no direct comparisons between colour measurements of different materials of different studies were made.

In the Calibra example, analysis of variance was conducted on the colour difference ΔE*values calculated between each final cement shade and its aquagel baseline using the ΔE* formula. These colour difference ΔE* values represent the amount of colour change (colour drift) caused by each cement shade from its individual baseline. Therefore, a comparison between these ΔE*values using ANOVA test and Tukey test for multiple comparisons compares different cement shades with respect to the amount of colour drift each will cause between its aquagel baseline and final veneer. Similarly, analysing ΔL*, Δa*, and Δb* values calculated between each cement shade and its baseline can be used if the change in each colour coordinate is to be assessed between different cement shades. This method allows for some variation among the baseline colours, as the final colour is only compared to the individual baseline.

Analysing the ΔE*, ΔL*, Δa*, and Δb*values calculated between each final cement shade and 1M1 shade tab (target) has shown different findings from those obtained when analysing ΔE*, ΔL*, Δa*, and Δb*values calculated between each cement shade and its baseline. This might be due to differences between groups which already exist in the aquagel base line, which may cause some misinterpretations, as final colour differences of porcelain veneers could be attributed to the differences in cement shades while already existing in the baseline. This method is sensitive to colour differences at baseline, and it is important to ensure that baseline colours are as close as possible in each group,

Alternatively, comparing the differences between different shades of Calibra resin cement can be achieved by analysing the absolute colour coordinates L*, a* and b* values of each experimental group. This analysis method has given similar results to those obtained when analysing ΔL*, Δa*, and Δb* values calculated between each cement shade and 1M1 shade tab for the significant differences in each of the colour coordinates L*, a* and b* values between different shades, but it cannot give any idea about the significant differences in overall colour difference ΔE* values. This method will also be very sensitive to differences in baseline colour.

Therefore, analysing ΔE*, ΔL*, Δa*, and Δb* values calculated between each cement shade and a target and the absolute colour coordinates (L*, a*, and b*) of each cement shade is considered one of the possible analysing ways providing baseline samples of exactly the same colour are attained, or in studies where the colours of the experimental samples are being compared without moving the colour coordinates of these samples from a specific baseline (e.g. Shereen's study [22]).

Presenting mean ΔE* values with confidence intervals can be useful for comparing the results to the perceptible and clinically acceptable thresholds, allowing assessment of statistical significance in comparison to the thresholds. Different ΔE* values were used as a threshold for clinically accepted colour difference (3.7, 3.3, 2.6, 2.5 and 2 units) in the dental studies reviewed, which could considerably change the clinical interpretation of the colour difference results. Therefore, it is important for researchers to try using the threshold which was been attained when studying the same materials and when using the same colour measuring devices. Additionally, presenting ΔL*, Δa*, and Δb*values calculated between each cement shade and its baseline using means and confidence intervals is very helpful to see the differences in each colour coordinate separately, adding to the overall understanding of the colour variables.

Within the limitations of this review, the following recommendations can be made for the analysis of colour variables in dental colour research:

1. Finding a reference, where possible, to compare the colours of the test samples; this reference can be, for instance, a control group of samples, consistent baseline, or a colour value that we are trying to attain.

2. ΔE* values and/or ΔL*, Δa* and Δb* values between the experimental groups and the reference can be calculated and presented using means and confidence intervals.

3. These ΔE*, ΔL*, Δa* and Δb* colour data can be analyzed (ANOVA test with an appropriate post-hoc pairwise test) to assess the differences between different experimental groups. Moreover, analysing the absolute (primary) colour coordinates L*, a*, and b* of the experimental groups can be conducted whenever possible.

4. Presenting ΔE* values using means and CI (confidence intervals) will always help to compare these differences to the perceptible and clinically acceptable thresholds with an appropriate statistical test if required, and presenting ΔL*, Δa* and Δb* values in the same way will aid to completely understand the differences in each colour coordinates.

Conclusion

Analysing the ΔE* and/or ΔL*, Δa* and Δb* values calculated between experimental samples and baseline can be the appropriate colour variable to be investigated in dental colour research. However, providing a consistent baseline or where no baseline is used, other colour variables can also be investigated. Presenting ΔE* values using means and CI is very useful to compare with clinically acceptable thresholds.

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