Gingival inflammation assessment by image analysis: measurement and validation

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Running title
Measurement of gingival inflammation

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ABSTRACT

Background and objectives. Gingival inflammation may be caused by injury or plaque related diseases and reduction of inflammation can be a useful indicator of gingival recovery. There has been little research on development of non-index methods to measure gingival condition. This study aims to investigate the reliability of the measurement of changes in gingival redness and swelling, using image analysis, and to compare this approach with an established method for assessing gingival overgrowth. **Method**. Twenty volunteers with gingival inflammation were recruited and digital images were taken. Duplicate measurements were made on the first visit by two examiners. At a subsequent visit following periodontal treatment, second images were taken. Gingival changes were determined by assessing redness and tooth surface area visible between the level of the inter-proximal papillae and the gingival margin. Tooth area measurements were compared with an established gingival inflammation method. **Results**. The method showed excellent reliability for both intra- and inter-examiner measurements of 0.968-0.998 and 0.769-0.947 respectively, according to the classification by Donner and Eliasziw (1) of Fleiss (2) coefficient of reliability. **Conclusion**. This technique proved a reliable method for investigating changes in gingival redness. High correlation was found for gingival encroachment when compared with an established method.

INTRODUCTION

Until the 1950's, gingival health was only assessed subjectively as good, medium or poor. Many indices have been described since, such as the P-M-A Index (3), which was later modified (4). This method relies on recording the location of inflammation in the

papilla (P) or gingival margins (M) and noting areas of attached gingivae affected (A). The World Health Organisation promoted the development of the Periodontal Index which was used widely up to the later part of the 20th Century (5). This index was the first used in longitudinal studies to show that scores lowered after treatment as the gingival inflammation measured was reversible.

Many current methods are derivatives of earlier existing systems such as Harris and Ewart's 0-3 system (6). Scores of 0 to 3 define increasing degrees of gingival encroachment over the tooth surface, and severity. Methods such as the photographic system produced by Ellis et al. (7) used photographs of patient's teeth that were projected on to a large screen. These were assigned a score indicating the encroachment level of the anterior papilla from 0-3. This method was applied to the labial surfaces of the anterior teeth. The scoring system was based on that developed by Seymour et al. (8) whereby the score 0 indicated no health problems, 1 defined slight granulation of appearance of the papilla, 2 indicated slight gingival encroachment over the tooth surface less than a quarter of the tooth width and 3 described severe encroachment over a quarter of the tooth width. This method used basic image analysis but relied upon the 3 stage scoring applied to each of 10 papillae regions (5 upper and 5 lower). The limitations of most indices are related to the subjectivity of examiner scoring and the level of method standardisation achievable.

This study aimed to investigate a method of measuring inflammatory changes in the gingival tissues that may be used to study the effects of treatment on individual patients and treatment outcomes in clinical trials, and to compare this approach with an established method for assessing gingival overgrowth (7).

METHOD

Patients

Twenty volunteers gave their written, informed consent to take part in this study conforming to the South Sheffield Ethics Committee regulations. The patients were chosen from those attending the Periodontology and Dental Hygiene clinics, Charles Clifford Dental Hospital, Sheffield. Each patient was seen on two occasions (pre- and post-treatment) and digital photographs were taken on each visit. The second visit was not less than one month after the first and during this time non-surgical periodontal treatment was provided by one of the Hygienists. This consisted of advice on plaque control, scaling and root surface debridement.

Imaging system

The acquisition apparatus described by Smith et al. (9, 10) includes a frame designed by the first author and constructed within the Department of Oral Health and Development, School of Clinical Dentistry, Sheffield. This frame rotates around a Cephalometric head positioning apparatus. It has a platform mounting for a 32-bit Kodak Nikon DCS410 Digital Camera (CCD Dynamic Random Access Memory (DRAM) imager, giving an ISO of 100, providing 1.5 mega pixel resolution in an array of 1012 x 1524 pixels, producing 4.6MB TIF files), with a 90mm high quality Elicar macro lens. The camera position can be adjusted and recorded for height and in forward/backward position to accommodate different facial sizes. The frame also supports two Portaflash 220 slave flashguns (Jessops, U.K.) with white opacity filters to soften illumination. Each light is covered by polarizing film, with the polarizing effect direction set the same for both flashes and at 90 degrees to a circular polarizing filter attached to the camera lens. A flashgun on the camera triggers the slave flashes. The

trigger flash is covered with exposed film so that only the infra-red light required to initiate the slave flashes is transmitted, so not affecting the controlled light supply. The whole frame can be rotated around the patient's head until correct alignment with the tooth of interest is obtained. Paralax was not a consideration as all repeats were taken under the same conditions.

Image analysis

After image acquisition using Adobe Photoshop (V5.02, Adobe Systems Ltd, Europe), images were measured as shown in Figures 2-3. A thresholding process automatically selected a pre-determined range of pixel values of red, from the total 256 available. This process was used to isolate a red disc of known size (Figure 1, incorporated in the images for colour and size calibration) and then the total gingivae visible on the image: the histogram option was used to give the mean red pixel value of each (Figure 2) which was then recorded for later subtraction from the red disc value. Calibration and analysis of images was carried out using Image Pro Plus software (V4.0, Media Cybernetics, USA). This process was repeated on the post-treatment images gained at the patients' second visits. Any slight differences in the image illumination or in patient position would be accounted for by always subtracting the standard red coloured disc mean red pixel value from that of the gingivae, as the mean value of the red disc should not change in ideal conditions. This method ensures that changes seen are duo to gingival changes not random or systematic errors.

All the red discs were cut from the same sheet of red articulating paper, using a sterilised hole-punch and were 6mm in diameter. The discs gave almost identical red pixel values when checked before use. One was attached using the patient's saliva, to the upper central left incisor to facilitate calibration in mm^2 of the labial surface of the

upper central incisors that is bounded by the level of the inter-proximal papillae and the gingival margin (Figure 3), the percentage of this area in relation to the total labial tooth surface could also be calculated if preferred (the shade of the red disc was not altered by the dampness from the tiny amount of saliva used for attachment).

For validation, comparison was made with an image analysis based method by Ellis et al (7) which has the benefit of being derived from an established method by Seymour et al (8).

Statistical methods

Descriptive statistics including the mean difference, standard deviation and standard error were calculated from the repeat measures of the proportion of tooth surface area described, red disc mean red pixel values and gingival mean red pixel values for both examiners. Bias was tested using a Student t-test and illustrated using Bland Altman plots produced for all variables to test for unwanted size- difference relationships (11).

A two-tailed paired t-test was performed between first and second attendance data, with a significance level of 95% being selected (checked for normality). This was to detect any significant differences in gingival swelling.

The reliability of the method used to measure the relevant area and the mean red pixel value of the gingival and red calibration disc, was calculated from duplicate images that were taken by each of the two examiners on the first clinical attendance of the patients (pre-treatment). The subjects were repositioned in the apparatus between repeat images

so that total system error could be assessed. Reliability was assessed using Fleiss' (2) coefficient of reliability (R), which accounts for biological variation.

Comparison was made between the image analysis and the Ellis et al, 2001 established scoring system using Pearson's product-moment correlation coefficient.

RESULTS

Table 1 presents the descriptive statistics for any measurement/operator bias for intra- and inter- operator reliability calculated to provide evidence for assessment of the reliability of the method including the average red calibration disc red pixel value, the average gingival redness pixel value and the portional tooth surface area. All p values are greater than 0.05 inferring no significant difference between repeat measures.

Fleiss' coefficient of reliability data is shown in Table 2. All the values indicate high or excellent levels of method repeatability and reproducibility.

The summary descriptive statistics for the first and second attendance can be seen in Table 3. These data were used to evaluate any changes between the first and second attendance measurements using a two tailed paired t test. Table 4 shows no significant differences were found.

Pearson's correlation coefficient for comparison of the two gingival encroachment methods was -0.798 significant at the 0.01 level (two-tailed).

DISCUSSION

The results in Table 1 show no significant bias was observed for any of the variables. This is also seen both from the reliability t test values ($p > 0.05$ to show no significant difference or bias between each measure) and that all the mean differences are less than 1.96 x the standard error. The Bland Altman plots produced no indicative regular data patterns or trends suggesting size/error relationships.

The reliability study showed that the red calibration disc and gingival redness values were the most reliable with excellent Fleiss coefficient of reliability R values of 0.968 to 0.998 (Table 2).

Subtraction of the red disc mean red pixel value from that of the visible gingival on all visits enabled any systematic differences to be accounted for. Therefore, the remaining change in gingival value could be attributed to changes in inflammation.

There was no evidence of a statistically significant difference at the 95% level between first and second visits (Table 4). A few of the cases in this study when seen after a year, showed slight gingival redness level changes and reduced coverage of tooth surfaces from the measurement of the tooth area. However, most cases showed little change in short term assessments. The lack of change in the gingival colour and area of a patient may be accounted for by failure to achieve effective professional root surface cleaning, poor patient compliance, medical conditions affecting the host response or medication having an adverse effect on gingival inflammation and encroachment. However, in the group of patients examined, whilst good improvements were seen for some patients, the overall results within the group may have been adversely affected by a number of patients having a poor response to treatment.

One individual typical of those investigated is presented in Figure 4. The gingival inflammation redness (average red pixel value) rose by 11.9, as the inflammation declined indicated by an increase in RGB value (as inflammation reduces the red level darkens giving an increase in the RGB average red pixel level and vice versa). The upper right central incisor however, showed a decrease in area between the gingival margin and inter-proximal papilla perimeter of 3.98mm^2 signifying inflammatory enlargement compared to the upper left central incisor that showed an increase in area of 0.36mm^2 signifying a reduced inflammatory response. Overall, the inflammation

level appears to have dropped with a localised increased inflammatory response around the upper right central incisor.

Comparison of our tooth area approach for assessing gingival encroachment and the Ellis et al, 2001 established scoring technique showed a strong correlation (-0.798), validating this part of the technique. The image analysis system, however, by design should be able to detect smaller changes in gingival encroachment levels due to its objective non index system approach.

The variables chosen for this study were derived with the current technology in mind and the need to provide objective results as far as possible. Therefore the choices of an assessment of colour and area change seemed reasonable. The standard disc was used as there are minute positional and illumination differences between images that cannot be totally removed even with our standardised system.

The authors accept that due to imaging restrictions there may be some subjectivity in the redness assessment due to selection of the area of interest although the reliability results proved sound. The authors also accept that this method can only assess the anterior part of the oral cavity and often there is severe inflammation in the posterior part.

Although the main inflammatory response is pronounced at and largely limited to the gingival margin the method used the red pixel values from the total gingival area. This was to include any subtle changes from other regions of gingival. As the method was reliable this inclusion should not mask the changes at the gingival margin.

CONCLUSIONS

The method is highly reliable, both for measurement of the tooth area within the perimeter of the inter-proximal papillae and the gingival margin, and assessing the

average RGB red pixel value. The method has proved easy to perform after initial training. A permanent database of images is created that are useful for objectively assessing reliability, reviewing extraneous results or for further research studies. The method does not require qualified clinicians unlike many of the existing indices.

This project did not note significant differences overall from the group but some individual cases did show changes.

Image analysis shows limitations in that it is restricted mainly to the anterior region of the mouth. For this and other previously stated reasons traditional clinical assessments and examinations would still need to be undertaken.

Many factors are involved in oral health assessment. This system could be used to give patients a motivating pictorial indication of their changing periodontal state as well as provide objective data to match those changes.

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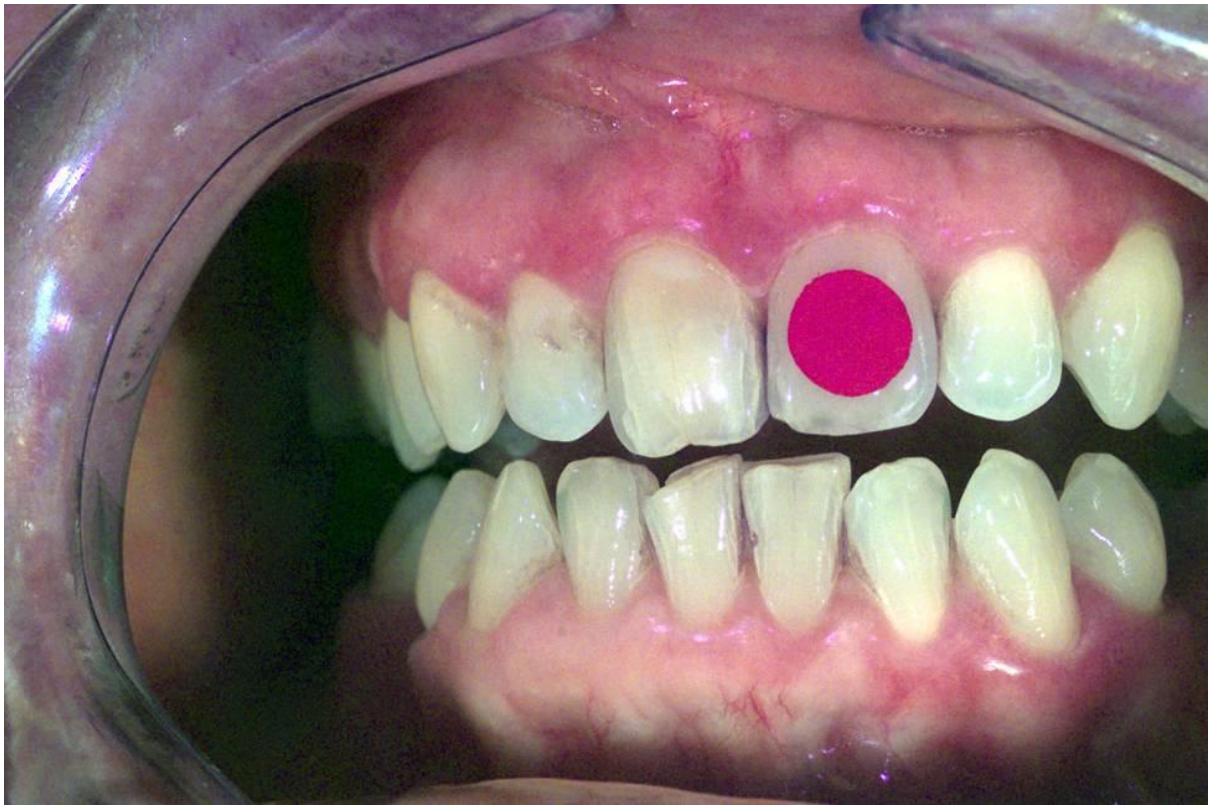
Legends to Figures

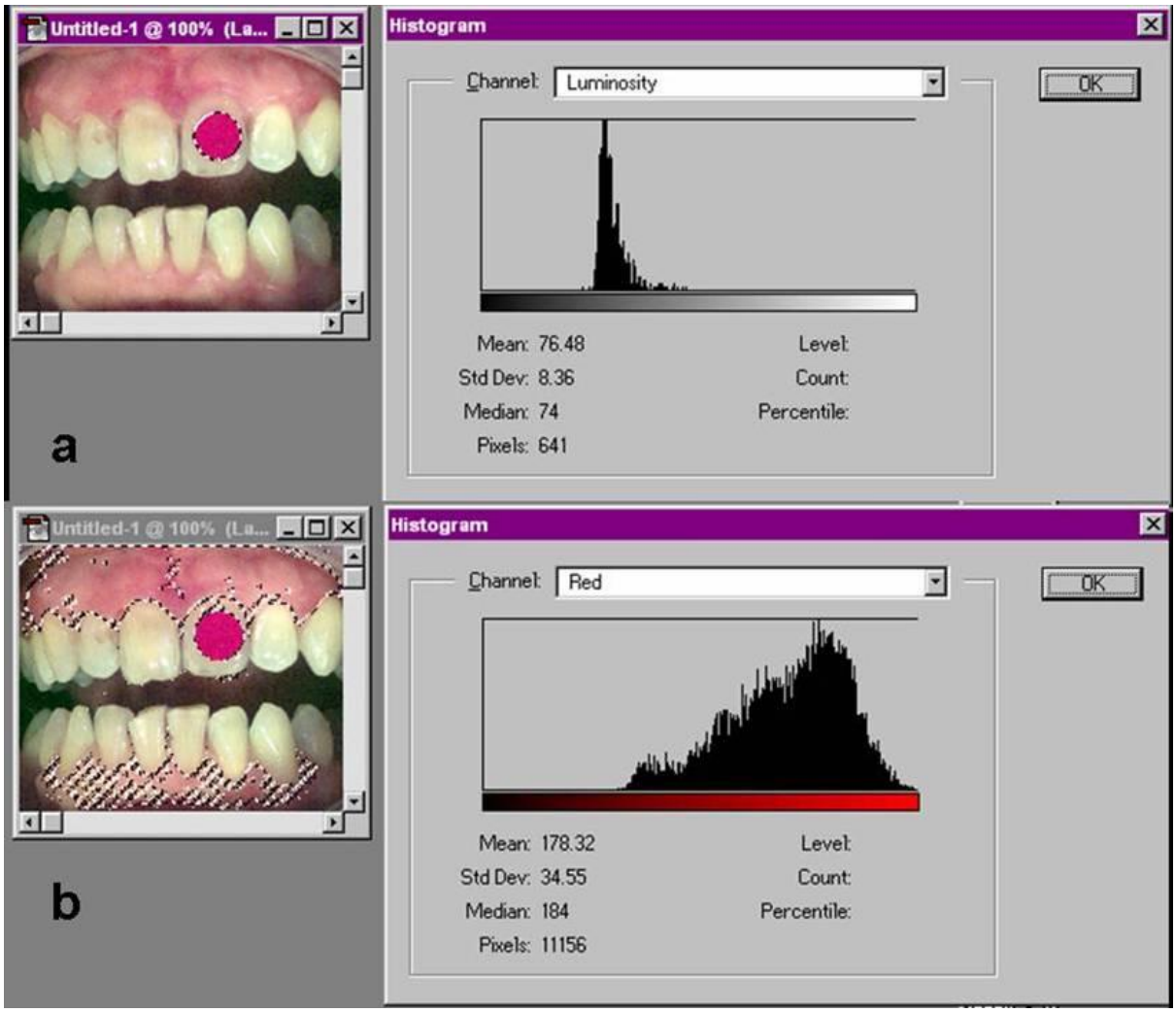
Figure 1. Image of the anterior teeth of a patient with gingival inflammation and with a red disc attached to the upper left central incisor.

Figure 2. (a) Image of isolated red dot and mean red pixel output menu, (b) image of the visible gingival area isolation by thresholding and area measurement in output menu after calibration.

Figure 3. Image of teeth showing portional tooth surface area measurement (mm^2) of an upper anterior tooth and output menu after linear calibration.

Figure 4. A patient, showing gingival colour change, imaged on two occasions with a month between visits**.**

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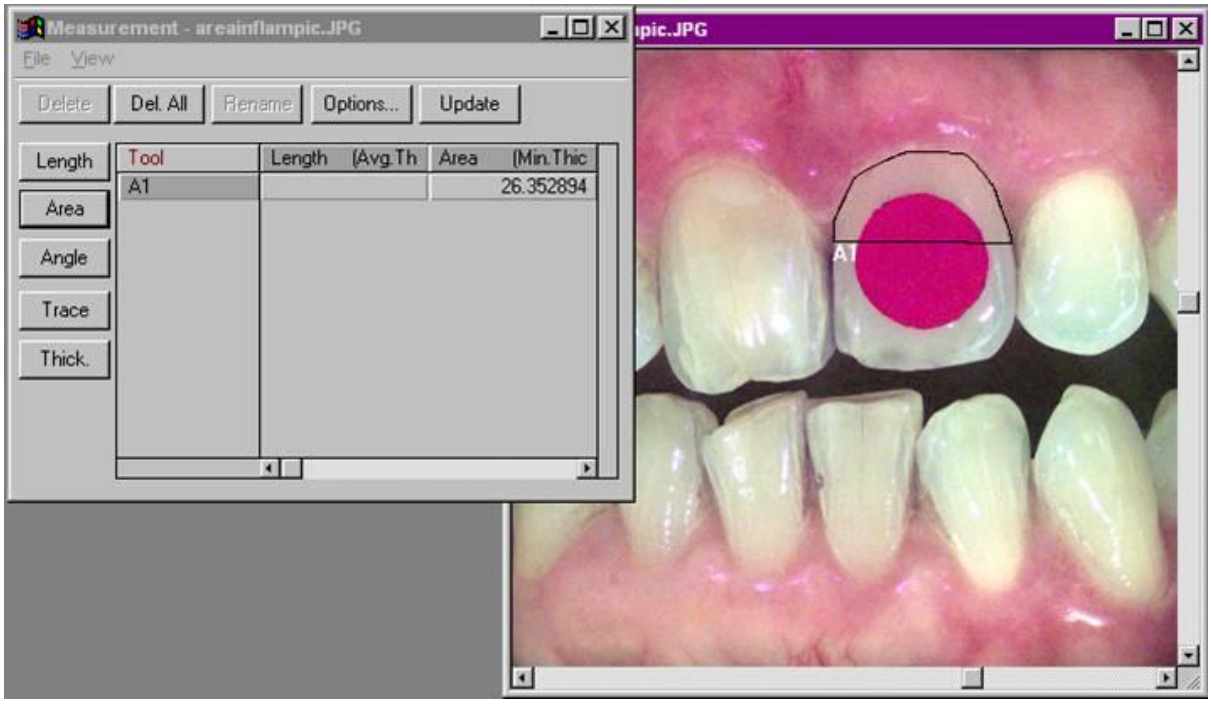
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Table 1. Descriptive statistics for measurement of upper right and left central incisor area for inflammation assessment and the average red RGB pixel level of the red discs and the visible gingivae (1st attendance).

Intra-operator repeatability	N	Mean Dif	SD	SE	t (p)
O1UR	20	-0.013	1.880	0.427	0.977
O1UL	20	0.1740	1.460	0.331	0.605
O1 Disc	20	0.024	3.560	0.814	0.977
O1 GING	20	0.626	2.850	0.637	0.340
O2UR	20	-0.235	1.450	0.325	0.479
O2UL	20	-0.682	1.710	0.357	0.072
O2 Disc	20	-0.132	0.800	0.182	0.478
O2 GING	20	0.230	0.900	0.199	0.264
Inter-operator reproducibility					
IUR	20	-1.327	2.983	0.667	0.061
IUL	20	0.820	2.445	0.547	0.150
I Disc	20	0.010	6.606	1.477	0.995
I GING	20	4.759	12.812	2.865	0.059

O1 or O2 = operator 1 or operator 2 intra-comparison for the measurement of the portional tooth surface area,
UR or UL = operator 1 or operator 2 intra-operator comparison for the upper right or upper left central incisors.
Disc = operator 1 or operator 2 intra-operator comparison for the mean red pixel level of the red disc.
GING = operator 1 or operator 2 intra-operator comparison for the mean red pixel level of the gingivae.
IUR or IUL = inter-operator comparison for the measurement of the upper right or upper left central incisor for inflammation encroachment.
I DOT = inter-operator comparison for the measurement of the mean red pixel level of the red dot.
I GING = inter-operator comparison for the measurement of the mean red pixel level of the gingivae.

Table 2. Fleiss' coefficient of reliability for measurement of upper right and left central incisor area for inflammation assessment and the average red RGB pixel level of a red disc and the visible gingivae.

AREA FOR INFLAMMATION STUDY	**Intra–operator**		**Inter-operator**
	Operator 1	**Operator 2**	
Upper Right Central Incisors	0.975	0.989	0.947
Upper Left Central Incisors	0.978	0.970	0.936
AVERAGE PIXEL RED LEVEL			
Red Disc	0.968	0.998	0.878
Gingival redness	0.987	0.998	0.769

R of 0.81-1.00 = Excellent reliability, R of 0.61-0.80 = substantial reliability (Donner and Eliasziw, 1987)

Table 3. Summary data for first and second attendance for the assessment of gingival redness and red disc average red pixel level.

Variable	**Occasion**	**N**	**Mean**	**± SD**	**SE**
Gingival redness (– red disc). (RGB mean red pixel value)	1st visit	20	-16.775	17.916	4.006
	2nd visit	20	-15.521	18.061	4.039
Upper right central incisor area (mm^2)	1st visit	20	21.759	9.900	2.214
	2nd visit	20	20.982	10.109	2.26
Upper left central incisor area (mm^2)	1st visit	20	22.952	8.120	1.816
	2nd visit	20	22.812	8.742	1.955

Table 4. Two-tailed paired t-test results for changes of gingival redness average red pixel level and tooth area before and after treatment.

Variable	N	Mean	± SD	SE	t test (p)
Gingival redness (-red disc value) (RGB mean red pixel value)	20	-1.254	22.92	5.12	0.809
Upper right central incisor area surrounded by gingiva) (mm^2)	20	0.777	4.717	1.055	0.470
Upper left central incisor area (surrounded by gingiva) (mm^2)	20	0.141	4.565	1.021	0.892