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Application of Mobile Photography with Smartphone Cameras for Monitoring of Early Caries Appearance in the Course of Orthodontic Correction with Dental Brackets

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Abstract
The objective of this research was observation of patients, who underwent orthodontic tooth alignment correction with dental brackets, for the detection of white spots, (early stage of caries) based on the digital photographs taken with a smartphone Sony Xperia S. Color reading was realized taking into account the adjustment of color features of a standard ceramic tile that was selected during the dental brackets installation period, the photo of which was taken simultaneously during the dynamic observation period. The color scale RGB was transformed into CIE L*a*b scale on the basis of correction of RGB components of smartphone image with correction coefficient, which was recalculated for tile surface RGB values. Consequent evaluation of lightness of suspected spots on the enamel served for the detection of white spots appearance. The expert appraisal showed sensitivity of proposed method between 88.7% and 96.2% and specificity between 68.4% and 84.2%. The positive predictive value was between 89.5% and 94.0%; and the negative predictive value was between 72.7% and 86.7%. Digital smartphone photo color corrected on the basis of comparison with tile surface permits to diagnose white spots appearance in patients with orthodontic tooth alignment correction.

Keywords: Orthodontia; Teeth brackets; Medical digital images; Tooth color.

Introduction

Digital images serve for distant diagnostics in dentistry [1], including those ones which are got with cellular phones [2]. But, the usage of digital images for identification of white spots, as an early developed caries marks, is not reliable as far as color characteristics are not correctly reproduced [3, 4]. Meanwhile, almost all patients which received orthodontic treatment are at high risk of precipitation or intensification of caries development [5]. Hence, working out mobile control of teeth color is actual for dentistry [4].

That is why, the objective of this research was evaluation of the possibility of distant (telemedical) control of teeth state in the pupils, who underwent teeth alignment correction with

dental brackets. The necessity to diagnose the early caries type – the demineralized white spots – was set a priority.

Material and Method

72 patients were observed during the research period, among whom 43 females and 29 males; the mean age was 13.1 $\pm$ 1.2 years old. All children underwent installation of dental brackets with the purpose of tooth alignment correction: 48 patients were diagnosed with diastema, and the rest had overcrowded teeth. All subjects provided written consent to research conduction applying a photographs transfer method. All investigations have been performed in accordance to ethics demands of commission on ethics at Odessa National Medical University.

In course of the research the assumption was made that color recognition by a smartphone camera is not reliable and can produce results not corresponding to the actual ones. The results depend on multiple factors, such as manufacturer settings of the camera chip, lighting of the object and color calibration [4]. Therefore in our research we resorted to creation of a standard ceramic tile, the color or which would correspond to the color of the teeth enamel (as a rule, of the upper medial incisors). This approach was realized applying a spectrophotometer (SP82OX, «TechkonGmbh», Germany), whereupon patients underwent a control shooting of the selected ceramic tile juxtaposed to the teeth enamel, which was used as a calibrating color image later on. For this purpose a section of a ceramic tile was fixed and/or temporarily fixed on the brackets during the shooting session.

Besides, the patients themselves passed a short interim training, where they were taught shooting their own teeth using a smartphone. The camera's lens was focused strictly on the study object. The distance between the camera and the study object was also rigorously controlled, since this factor was also important for correct color recognition of the studied object. In our research we followed the recommendations on using a smartphone camera at a 20 cm distance from a shooting object.

In the current research the smartphone Sony Xperia S was used that is notable for its satisfactory color recognition features. For color analysis the images were processed with Adobe Photoshop CS6, and the results were interpreted in RGB scale format.

Correction of the range of colors of the studied tooth enamel was conducted as follows:

In the first stage the respective measurements of control values - Rc, Gc, and Bc were made for the ceramic tile used later as a "calibrating image". It should be noted that the initial ratios of enamel indicators (R_1; G_1; B_1) determined at the stage of identification of tile, and the calibrating image indicators (Rc; Gc; Bc) were at a certain possible minimum, because the indicators selection was conducted basing on the color similarity principle:

R_1/ Rc = const R (min); G_1 / Gcconst G (min); B_1 / Bcconst B (min) (1)

After selection of the calibrating tile the color of the object was measured using digital photographs taken with a smartphone. As a result, respective values Rc^x; Gc^x; Bc^x for the calibrating tile itself were obtained, which differed from the spectrophotometry control values (1).

Therefore in order to adjust the obtained values to the spectrophotometry determined indicators the correction factors were calculated:

$Rc^x/Rc = R^x$; $Gc^x/Gc = G^x$; $Bc^x/Bc = B^x$ (2)

In the last stage the color indicators obtained through the photographs analysis (Rn; Gn; Bn) were multiplied by the correction factors values:

Rn x R^x= Rf; Gn x G^x=Gf; Bn x B^x= Bf (3)

(f- final).

The obtained in the last stage (3) values were used for translation into CIE L*a*b* scale [6] that was used for calculation of the whiteness (brightness) value of the studied local zone of the enamel surface.

Images have been investigated by three experienced dentists (experts) and they generated their conclusion on the diagnosis of early developed caries via identification of white spots. Hence, the image quality was assessed by a single dentist as either "presence" or "absence" of white spots. Later on during next week all patients were investigated by dentists and final conclusions have been compared with those ones made using photos.

Such indices as sensitivity, specificity, positive predictive value and the negative predictive value have been calculated [1]. All data sets were tested to verify that they fulfilled requirements for a normal distribution. One-way ANOVA followed by Newman-Keuls test was conducted to compare differences between groups, and a *P* value 0.05 was deemed significant.

Results

The method of white spots diagnostics via smartphone images was made during the period starting from the second up to fourth months of monitoring of patients with orthodontic treatment. At the end of this period all patients have been thoroughly examined by dentist and verified presence of white spots was recorded in 53 patients, while 19 patients had no signs of early caries.

Table 1. The results of expert review of early caries (white spots) diagnostics based on digital photographs of tooth alignments (%)

Experts (by №№)	Sensitivity (%)	Specificity (%)	Positive predictive value (%)	Negative predictive value (%)
Without correction of digital image RGB values				
№1	45 (84.9)	7 (36.8)	78.9	46.7
№2	38 (71.7)	9 (47.3)	79.2	37.5
№3	41 (77.4)	5 (26.3)	74.5	29.4
Mean (by experts)	78.0	36.8	77.5	37.9
After correction (usage of recalculated coefficient)				
№1	51 (96.2)	13 (68.4)	89.5	86.7
№2	47 (88.7)	16 (84.2)	94.0	72.7
№3	50 (94.3)	14 (73.7)	90.9	82.3
Mean (by experts)	93.1	75.4	91.5	80.6

The conducted research showed that sensitivity of white spots diagnostics using digital photographs transferred from a smartphone was 71.7% to 84.9% (the mean 78.0%). Moreover, the number of false positive diagnoses comprised 8 to 12 cases (10 on average). The sensitivity of the method improved by 15.1% if the photograph was adjusted using the selected earlier control tile, and its average value was 93.1%. The number of false negative diagnoses in this case dropped and comprised 2 to 7 cases (5 on average).

The diagnosis specificity indicator in absence of color features correction comprised 26.3% to 47.3%; and the number of false positive diagnoses was respectively 10 to 14 cases (12 on average). At the same time, if the correction according to the developed method was used, the specificity increased more than twofold; and the number of false positive cases was 3 to 6 (5 on average).

The positive predictive value comprised 77.5% on average, when diagnostics by digital photographs was used without color adjustment, while the negative predictive value comprised 37.9% on average.

After the color adjustment according to the developed method, the positive predictive value increased by 14.0%, and the negative predictive value increased by 2.1 times (Table 1).

Hence, the obtained results showed that application of the developed method of early caries (white spots) diagnostics using the suggested technology of color calibration of the smartphones in orthodontic patients (Fig. 1), who are being observed during the period of wearing the dental brackets, allows a significant improvement of the diagnostics efficiency.

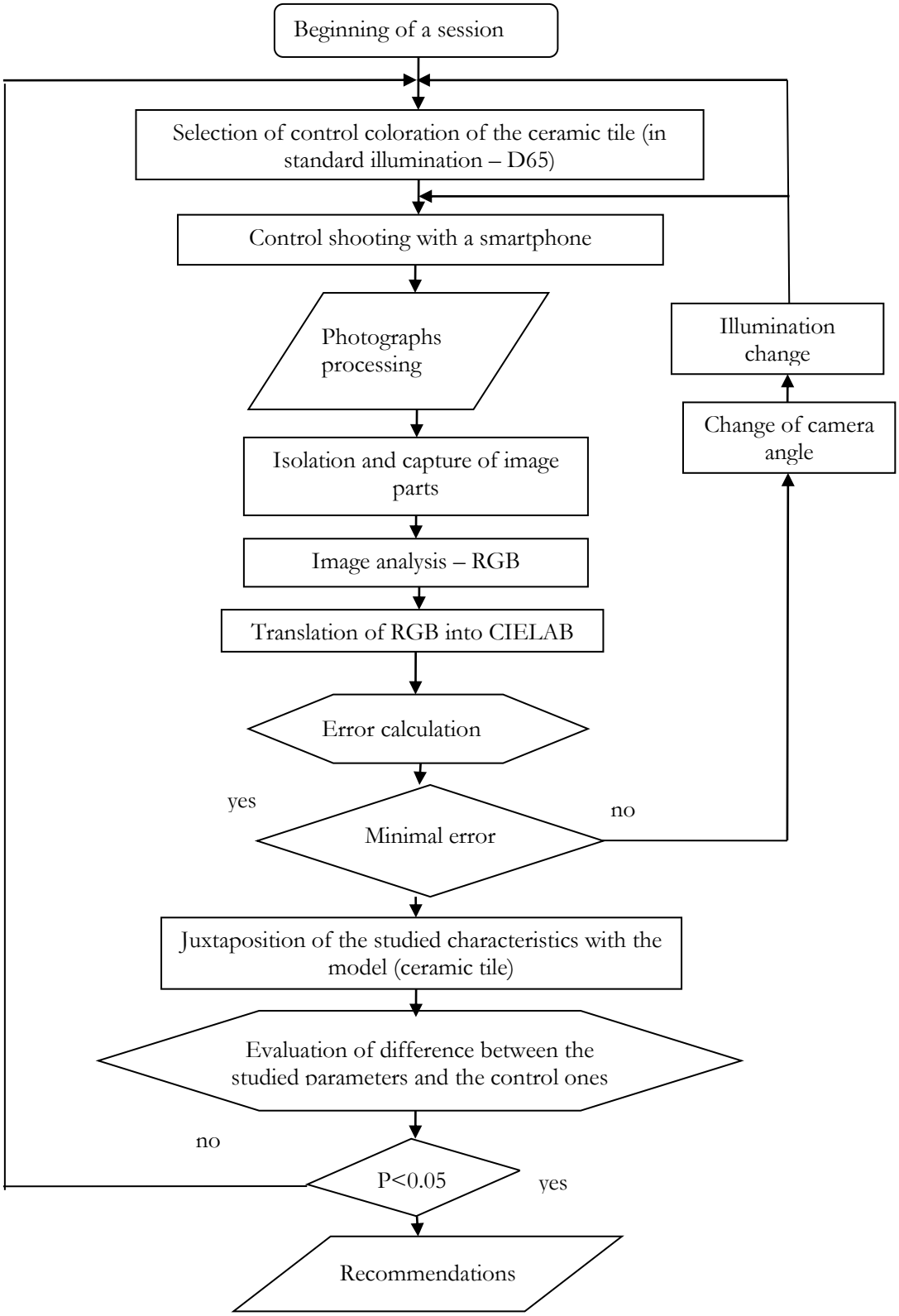

Figure 1. Algorithm of enamel color evaluation in early caries diagnostics

Discussion

Hence, the presented results show that application of the smartphone Sony Xperia S for tooth enamel color reading is associated with a certain distortion of the range of colors, which can be explained by the constructive and technical parameters of the smartphone, as well as with the shooting settings, namely, camera angle, illumination, and distance to the object being photographed [4]. Taking into account the necessity of introduction of the correction factor for respective colors, the selection technique of the control (calibrating) ceramic tile that was used in the current research, the color of which corresponds to the patient's natural teeth enamel color during her first visit before brackets installation, showed effectiveness of the subsequent color analysis of the obtained photographs in white spots diagnostics. Furthermore, the applied correction algorithm allows improvement of specificity and sensitivity of diagnostics of the focal enamel demineralization in comparison with a conventional expert analysis of digital photographs.

Realization of such approach complies with the view on the necessity of smartphones calibration for evaluation of color reading and proves a fundamental opportunity of usage of respective mobile diagnostics of enamel state in patients with dental brackets. It is also important to note that for the purpose of color correction (calibration) the optical characteristics of the very brackets elements can also be used, as well as the modified brackets with fixed during the observation period "control" ceramic samples.

An additional opportunity provided by the mobile monitoring of patients, which is quite perspective is confined to evaluation of soft tissues color and distant diagnostics of paradontosis.

In general, the obtained results show that digital photographs of tooth alignments, as well as of the soft parts, can be applied for distant (telemedical) consulting of patients receiving orthodontic treatment, which can be important from the cost-effectiveness point of view of providing orthodontic services to the general population.

Conclusions

Usage of spectrophothometry determined control color tile for the tooth should be used for the recalculation of correction coefficient for teeth color identification of smartphone made photos of teeth and diagnostics the presence of white spots as an early developed caries.

Smartphone photos could be helpful for dynamical control of teeth state in patients which recieved orthodontic treatment.

Conflict of Interest

The authors declare that they have no conflict of interest.

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