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Original Research Article

Correlation between dental crown's color and pulse oximetry interpretation in teeth submitted to bleaching procedures

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Abstract

Objective: To evaluate the correlation between the dental crown's color and the pulse oximeter result in healthy teeth before and after 30 days of the end bleaching procedures. **Material and methods:** The dental crown's color of 70 healthy maxillary central incisors were evaluated using a spectrophotometer and the oxygen saturation level of the pulp was recorded using a pulse oximeter. The bleaching was performed using the combined technique, with 35% hydrogen peroxide bleaching gel, in the office stage, and 10% carbamide peroxide, in the at-home, for 16 days. The variables symmetry was verified by the Kolmogorov Smirnov test, and the quantitative variables described by mean and standard deviation. The correlation between quantitative variables was established using Pearson's correlation coefficient. The significance level considered was 5%. **Results:** A significant change was observed between values recorded by the pulse oximeter before (85.0% ± 4.1) and after (86.4% ± 2.3) 30 days of the end. Thirty days after the end of the bleaching procedures, the dental crowns were lighter with the difference between L*s equal to 1.4, more greenish with a difference between a*s equal to 1.3,

and more bluish with a difference between b*s equal to -7.2. There was no correlation between the values of coordinates L*, a* and b* and the results recorded by the pulse oximeter in the initial period, respectively, or 30 days after the bleaching procedures, respectively. **Conclusion:** Changes in pulse oximeter recordings did not correlate with the change in the dental crown's color promoted by bleaching procedures.

Introduction

The accurate diagnosis concerning the pulp condition in teeth compromised by caries, trauma or restorative procedures is fundamental for the appropriate treatment establishment [14]. Searching for the diagnostic tools improvement, evaluative studies about the pulp tissue vascularization have been carried out using spectrophotometry, laser doppler flowmetry and pulse oximetry [14, 25, 34], being the pulp vitality usually significant for the vascular supply integrity of the dental pulp [3].

Clinical studies on sound teeth with pulse oximeter record a varying average levels of oxygen saturation in the pulp [8]. In a systematic review and meta-analysis study, Lambert *et al*. [41] found average levels of oxygen saturation in central incisors, lateral incisors upper canines: 84.94%, 89.29% and 89.20%, respectively; while in maxillary premolars the average level observed was 86, 2% [25], in maxillary molars the level was 83.59% and in mandibular molars it was 86.89% [24]. These variations have been associated with factors such as dentin-enamel thickness [63], dental group [24], age group [25] and presence or absence of light [63].

Solda *et al*. [64] and Lima *et al*. [44] monitored the pulp oxygen saturation level in the sound maxillary central incisors were monitored before and after bleaching procedures. Significant variations in saturation values have been attributed to vascular changes due to possible hydrogen peroxide penetration through the dentin and the pulp reach [12, 13].

However, the color change effect on the dental crown caused by bleaching procedures on the valuation recorded by the pulse oximeter was not considered. Aesthetic dental treatments such as tooth whitening, which can modify the teeth color [18], promote greater passage of light through the tooth structure [5] and changes in the enamel surface morphology with increased surface roughness [19]. The pulse oximeter, which uses optical technology, can be affected by these changes.

There are investigative studies which show how the nail polish colors can affect the oxygen saturation measurements taken by the pulse oximeter on the finger [32, 70]. Decreases in pulse oximetry readings of 3% to 5% have been reported, depending on the absorption of red and infrared light when green, black, red, blue, or brown colored nail polishes are present [1, 32, 54]. However, some studies claim that the observed changes are not clinically significant [21, 54].

Whereas, in teeth, according to Sproull [65], the basic color variation range goes from yellow to reddish-yellow, however, the definition of the tooth color is a complex phenomenon, with many factors such as lighting conditions, translucency, opacity, light diffraction, brightness, human eye and brain, influencing the complete perception of color [35, 36].

The colors determination in dentistry has been analyzed under two prisms, visual and instrumental. The visual method is performed on a subjective comparison between the patient's teeth and a predetermined color pattern, using paper, colored porcelain or color guides, while the instrumental method uses colorimeters, spectrophotometers or image analysis software [36, 51]. Studies show that spectrophotometers are objective and reliable [11, 23, 37] and are useful in measuring tooth surface color. Furthermore, they are not affected by ambient light [33] or by the object's metamerism [6].

The pulp diagnosis condition is still one of the biggest challenges in the dental clinic, which justifies the advancement of research with the pulse oximeter, through the perspective, especially, of diagnosing pulp vitality in hospitalized, pediatric, or psychologically disorder patients, without the unpleasant painful sensation imposed by thermal tests [63]. In addition to being non-invasive, objective, and reproducible, the pulse oximeter has greater patient acceptance and cooperation [17, 62].

In this context, it is opportune to identify and analyze potential clinical factors that may interfere with the pulse oximeter results, consequently, in the establishment of an accurate dental pulp condition diagnosis. Therefore, this study evaluates the correlation between dental crown's color and the pulse oximeter result in sound teeth before and after bleaching procedures.

Material and methods

Sample calculation

According to the sample calculation, it would be possible within 62 teeth to detect a statistically significant correlation coefficients, between the dental crown's color and the pulse oximeter result, in moderate magnitude (r=0.40) considering a power of 90%. The sample size established for this study was 70 participants with an evaluation of 1 (one) tooth per participant.

Experimental design

It was a clinical trial with measurement of two numerical variables, the dental crown's color and the pulp oxygen saturation, in two moments, before and after 30 days of the conclusion of the bleaching procedures. Each variable was evaluated by different examiners and the access to all data only occurred at the end of the experiment, following the Consolidated Standards of Reporting Trials (CONSORT) recommendations. The present study began after the approval by the Research Ethics Committee of the Federal University of Goiás, CAAE n. 52047115.2.0000.5083.

Individuals who agreed to participate in the study underwent anamnesis, extra and intraoral physical examination and periapical radiography, emphasizing the areas corresponding to the upper central incisors. The physical examination included inspection, palpation, percussion tests, evaluation of the periodontal health (absence of mobility, recession or loss of periodontal attachment) and cold thermal testing, carried out under a relative isolation. For this test, Green Endo Ice refrigerant gas (-26.2ºC, Hygenic, USA) was used, observing whether the response was positive or negative. The response time in seconds was recorded using a digital stopwatch. The response was considered negative after two fifteen-second applications of the refrigerant gas with a two-minute break between each application, without any manifestation of painful symptoms by the patient. For the radiographic examination, a Cone Indicator radiographic positioner for adults was used (Indusbello, Brazil), an Express phosphor plate reader (Instrumentarium Dental, Finland) and a Timex 70E radiographic device (Gnatus, Brazil) with exposure time of 0. 5 seconds.

The inclusion criteria were patients between 18 and 25 years old, who had a healthy upper right central incisor, with normal periodontal ligament space, periodontal health, complete rhizogenesis, absence of nodules, pulp obliterations, resorptions and fractures, and also presented teeth with color A2 or darker compared to the Vita Lumin® scale (Vita Zahnfabrik, Bad Säckingen, Germany). There were excluded from this study: patients whose teeth had carious and non-carious lesions, such as abfraction, erosion and abrasion, with the presence of cracks or clinically visible enamel defects on dental surfaces, also patients who wore fixed orthodontic braces and had previously undergone tooth whitening, presence of severe tooth darkening (tetracycline staining or fluorosis, endodontic treatment), presence of parafunctional habits, presence of oral pathology, smokers, pregnant women, lactating women, and patients with a history of systemic diseases or drugs, history of occlusal trauma or dental trauma, and teeth with a negative response to the thermal test.

Dental crown shade evaluation

The area selected to evaluate the dental crown's color was the buccal surface middle third from the upper right central incisor. Before measuring with the spectrophotometer, the molding of the selected tooth was performed with a dense silicone condensation paste (Perfil Cub®, Vigodent, Rio de Janeiro, RJ, Brazil) to prepare a pattern guide for the color measurement site [45].

On the buccal surface silicone guide outer portion, a fenestra was created by a sharp-edged metallic device, with a size compatible to the active extremity of the spectrophotometer and the position corresponding to the middle third of the teeth buccal surface, according to the technique recommended by Marson *et al*. [45]. For the evaluation, the Vita Easyshade® Compact device (Vita Zahnfabrik, Germany, 2009) was used. The spectrophotometer extremity was placed over the middle third of the tooth buccal surface, and the color was evaluated three times, the result being the average of the values.

To ascertain the color, the digital spectrophotometer parameters were used according to the CIE Lab system, where L* represents the object luminosity measurement, and a* and b* represent the spindle colors: red-green and yellow-blue axes, respectively.

To verify the influence of each coordinate on the color difference 30 days after the tooth whitening procedures, each coordinate was analyzed separately, according to ABNT NBR 15077 [4]: L*final - L*initial: > zero: more clear; L*end - L*start: < zero: darker; a*final - a*initial: > zero: more reddish; a*final - a*initial: < zero: more greenish; b*final - b*initial: >zero: more yellowish; b*final - b*initial: <zero: more bluish.

All evaluations to set the dental crown's color were carried out by a single researcher, a specialist in Restorative Dentistry, with experience in using a spectrophotometer, under identical indirect lighting conditions and using the same equipment, without the use of a reflector.

Measurement of the pulp's oxygen saturation level

The oxygen saturation level of the pulp was measured using a pulse oximeter, pediatric BCI (model 3301, Smiths Medical PM Inc., USA) and a SYS 103 sensor, with a prefabricated adapter made according to the study by Giovanella *et al.* [27].

The research participant seated, with the arm positioned on the equipment, was instructed to remain still during the assessment. After confirming the absence of nail polish on the participant's little finger, the participant was positioned to measure the oxygen saturation level (%) and pulse (bpm). Two oxygen saturation level measurements were taken, the first measurement being performed 30 seconds after the sensor was fitted on the finger and the second measurement 30 seconds after the first.

After measuring the oxygen saturation in the finger, the collection of the pulp saturation level was performed under isolation with cotton rollers and a saliva sucker, the drying of the involved dental surfaces and in the absence of light from the reflector. Patients were positioned lying down and instructed to stay still throughout the test. The prefab adapter was fixed to the device sensor and taken to the tooth to the evaluation, taking care for the light to reach the middle third region of the crown and to provide parallelism between the emitting diode and the photodetector. Two measurements were taken to calculate the average oxygen saturation, as described above, the final result being the average from the two values.

The measurements were performed with the room temperature controlled at 24ºC (± 1ºC) and ambient lightning. The pulp oxygen saturation level was evaluated before the first whitening gel application and 30 days after the tooth whitening procedures, by a single researcher, specialist in Endodontics, with experience in pulse oximetry.

Tooth whitening procedures

One week before starting the whitening procedure, the participants had their first appointment, in which prophylaxis, guidance on oral hygiene and dietary habits were performed. During these appointments, dental arches were molded with Plastalgin Type II alginate (Zhermack, England, UK), mold disinfection and casting with Type III stone plaster (Asfer Indústria, Brazil) for the manufacture of whitening trays with silicone plate 1mm thick in a vacuum plasticizer (PlastVac P7, Bioart Equipamentos Odontológico Ltda, Brazil). Furthermore, all patients received a tube containing toothpaste and were instructed to use the same in all brushings. It was also advised to perform a manual smear for one minute with the dentifrice on all teeth (to minimize possible tooth sensitivity) and abundant washing with water before inserting the tray with homemade whitening gel.

The bleaching procedures were performed using the combined technique, in-office and at-home, with a 35% hydrogen peroxide bleaching gel application (Total Blanc Office® H35, Nova DFL, Brazil) at the office stage, following the manufacturer's instructions, and with 10% peroxide carbamide (PC) (Total Blanc Home® C10, Nova DFL, Brazil) in the homemade stage. To protect the soft tissue, a lip and tongue retractor and gingival barrier from the Total Blanc Office kit (Nova DFL, Brazil) were used.

The 35% hydrogen peroxide gel was applied on the anterior and premolars teeth surface, maintaining the specified time (two applications of 20 minutes). After bleaching, the gel was sucked and the teeth cleaned with cotton, then washed with a jet of water. All clinical interventions were performed by the same operator, a specialist in Restorative Dentistry. The bleaching agent PC 10% was used in an individual tray for two hours a day, using the at-home bleaching technique, for 16 days.

Statistical analysis

The data were recorded into Excel and later exported to SPSS v. 20.0 for statistical analysis. The variables symmetry was evaluated using the Kolmogorov Smirnov test. Quantitative variables were described by the average and standard deviation and student T test was used to compare paired samples. The correlation between quantitative variables was established using the Pearson correlation coefficient. A significance level of 5% was considered.

Results

The data for this study were collected from 70 healthy right maxillary central incisors, corresponding to patients of both genders (63.33% female and 36.67% male), whose age average was 21.1 ± 2.2 years, with an average level of oxygen saturation in the finger of 97.75%

The midpoint from the results recorded by the pulse oximeter and the values of coordinates L*, a* and b* presented by the spectrophotometer, initially and 30 days after the bleaching procedures, are presented in table I and illustrated in figure 1.

Table I – Description of the average and standard deviation from the results recorded by the pulse oximeter (%) and the values of coordinates L*, a* and b* detected by the spectrophotometer (units) before and after 30 days the tooth whitening

Variables	Average ± *dp* Initial	Average ± *dp* 30 days	p
Oxygen saturation (%)	85.0 ± 4,1	86.4 ± 2,3	0.009
L*	89.0 ± 2,8	91.2 ± 2,6	<0.001
a*	-1.7 ± 0,7	-3.0 ± 0,6	<0.001
b*	20.7 ± 3,2	13.5 ± 2,5	<0.001

Data presented as average ± standard deviation and compared by Student's t test for paired samples

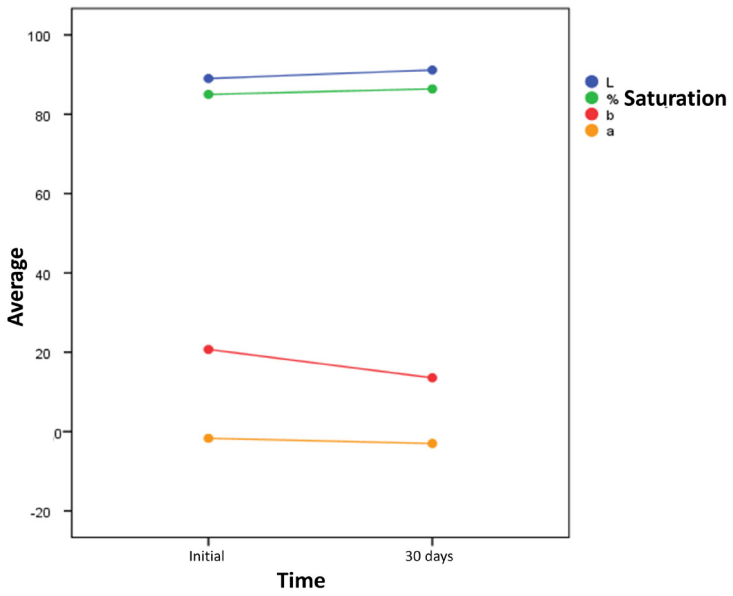

Figure 1 – Graphic representation from the average pulse oximeter results (%) and the values of coordinates L*, a* and b*, evaluated by the spectrophotometer (units), measured at the initial times and after 30 days after the bleaching procedures

A statistically significant change can be observed in the values recorded by the pulse oximeter before and 30 days after the bleaching procedures, and also between the color coordinates values detected initially and 30 days after the tooth whitening conclusion.

The influence evaluation of each coordinate on the color difference, according to ABNT [33], showed that 30 days after the whitening procedures, the teeth were lighter since the difference between L*s was equal to 1.4, more greenish since the difference between a*s was equal - 1.3, and more bluish, b* equal -7.2.

There was no association between the values of coordinates L*, a* and b* detected by the spectrophotometer and the result recorded by the pulse oximeter in the initial period, as can be seen in figure 2. The initial coordinate L* was correlated with the result of the oximeter pulse rate of r= -0.22 (p = 0.070), aa* of r=0.02 (p=0.873) and b* of r=0.11 (p=0.357).

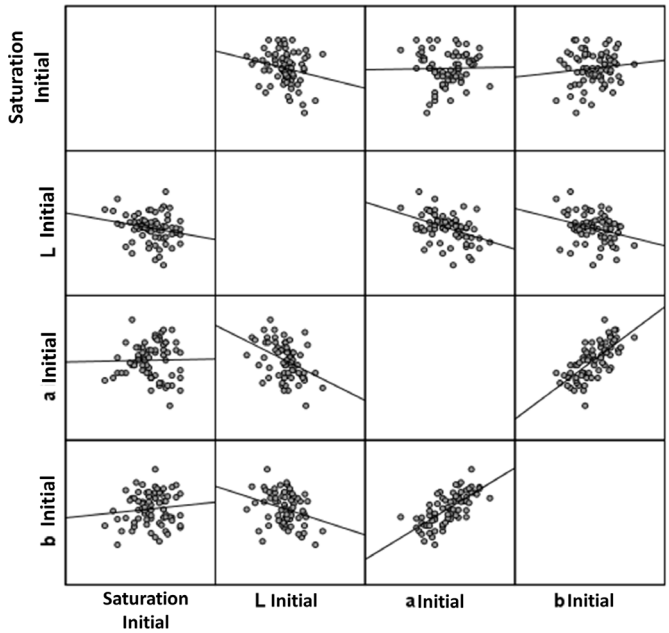

Figure 2 – Graphic representation demonstrating the absence of correlation between the pulse oximeter result (%) and the values of the coordinates L*, a* and b* (units) presented by the spectrophotometer, before the tooth whitening procedures

After a period of 30 days following the tooth whitening procedures, there was also no correlation between the pulse oximeter result and the coordinates recorded by the spectrophotometer. The L* coordinate showed a correlation with the pulse oximeter result of r= -0.20 (p=0.102), aa* of r=0.01 (p=0.931) and b* of r= -0.12 (p=0.34), as shown in figure 3.

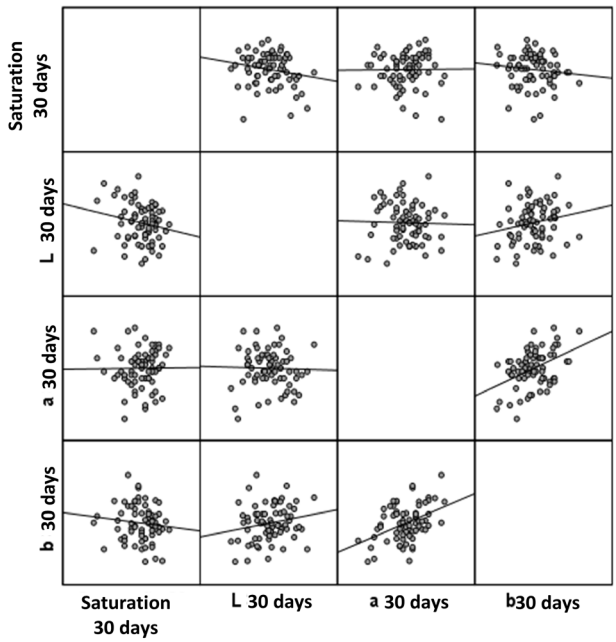

Figure 3 – Graphic representation demonstrating the absence of correlation between the pulse oximeter result (%) and the values of the coordinates L*, a* and b* (units) presented by the spectrophotometer, 30 days after the tooth whitening procedures.

Discussion

A statistically significant change was verified between values recorded by the pulse oximeter before (85.0% ± 4.1) and after 30 days after the bleaching procedures (86.4% ± 2.3), in agreement with the results 84.76% before and 86.52% after 30 days, reported by Lima *et al*. [44]. In this study, which oxygen saturation was evaluated several times, it was observed that there was a significant reduction in oxygen saturation immediately after dental whitening in the office, variation in levels during at-home whitening procedures and an increase 30 days after the treatment. Similar results were found in the study by Solda *et al*. [64] which the initial oxygen saturation (85.0%) was reduced soon after tooth whitening, returning to baseline levels 30 days after the bleaching procedures. These results have been justified by vascular changes observation after the tooth whitening, such as inflammatory infiltrate, dilated and congested vessels, disorganized pulp, reactionary dentin deposition and some necrosis points, in an animal study [12]. Furthermore, there are trans-amelodentinal cytotoxic effect reports of bleaching agents on odontoblastoid cells resulting in reduced cell metabolism [59]. The increase in the level of oxygen saturation after bleaching sessions has been justified on studies by Cartagena *et al*. [10] per means of laser doppler, these studies showed an increase in the initial pulpal blood flow 7 days after the bleaching procedures, in sound central incisors, with values higher than the initials, and by Vaz *et al*. [68] in a microscopic study of human molar pulp, it was observed an increase in the number of blood vessels 7 days after the end of bleaching treatments.

However, none of the aforementioned studies considered changes in the dental crown's color or possible structural changes in enamel and dentin due to bleaching procedures, which could act as potential interference factors in pulse oximeter recordings.

The two mineralized tissues, enamel, and dentin which make up the dental crown, do not present uniform thickness and are, respectively, translucent, and opaque structures [26]. These characteristics influence both the dental crown's color and the pulse oximeter recordings [63], that is, when the light hits the tooth, part of it is reflected by the enamel surface and part passes through it on the dentin. In the dentin, the light is either absorbed reaching the pulp tissue, and then the pulse oximeter receptor, or is reflected back to the enamel, crossing it and impregnating the observer's vision [52, 67].

Some conditions can alter the light transmission and reflection through the dental crown, such as: dehydration, as a result of the replacement of water by air around the prisms [58], the texture or the surface roughness, and different curvatures between incisors, canines, premolars and molars that reflect light differently, modifying the optical properties of enamel and dentin in the spectral ranges of ultraviolet, and red and infrared used in pulse oximetry.

Increased brightness is one of the most expected and important optical effects when the tooth whitening treatment effectiveness is analyzed [22]. These study results demonstrated that the bleaching procedures changed the dental crown's color with increasing luminosity, making it more bluish and greenish, visibly lighter. A statistically significant change was observed between the initially detected values from the color coordinates (L*= 89.0 ± 2.8; a*= -1.7 ± 0.7; b*= 20.7 ± 3.2) and 30 days after the tooth whitening procedure (L*=91.2 ± 2.6; a*=-3.0 ± 0.6; b*= 13.5 ± 2.5).

Most bleaching systems use hydrogen peroxide as an active oxidative agent to degrade organic compounds that cause stain on the dental crown [57]. Due to its low molecular weight, hydrogen peroxide diffuses into the tooth's organic matrix, breaking down and producing free radicals, which in turn act on the organic compounds, leading to whitening results [55]. According to Carey [9], whitening gels act by breaking unsaturated carbon bonds in pigment molecules, making them smaller and less complex, reducing absorptive capacity and increasing light reflection and transmission. These factors may have contributed to the change observed in the values recorded on this study by the pulse oximeter, in bleached teeth. Since the oximetry measurements were performed 30 days after the bleaching procedures, when supposedly the bleaching agents are no longer acting and the pulp's blood circulation has already returned to normal, alterations in oximetry could be corroborated by the color change.

Furthermore, several in vitro studies reveal that bleaching agents used in bleaching techniques can cause morphological changes in mineralized structures [30, 71]. Decreased dentin microhardness [43], increased permeability [20] and change in surface morphology [71] have been reported after bleaching procedures. Vilhena *et al*. [69] analyzed the morphological changes resulting from tooth whitening, and observed that after 14 days, there is the onset of changes on the whitened enamel surface, with slight prismatic enamel exposure, central

portion loss from the prisms with maintenance of the interprismatic limits. The need for studies to assess the type of dental crown surface interference in the reflectance and light transmittance of the pulse oximeter is evident, so that its accuracy in diagnosing the oxygen saturation level of the pulp can be accurately determined.

No correlation was found between the values of coordinates L*, a* and b* and the results recorded by the pulse oximeter in the initial period or 30 days after the bleaching procedures. These findings suggest that the color change on the dental crown caused by bleaching procedures did not systematically interfere with pulse oximeter recordings. These results could be justified by studies [69] which show in despite the chemical changes that result in dental crown increased luminosity, hydroxyapatite crystals maintain a mineral structure organizational pattern, not having changes in the enamel structural organization and dentin after tooth whitening, differently from what happens with age.

In the present study, upper central incisors of participants with an age level of 21.1 ± 2 were evaluated, with the objective of minimizing anatomical varieties, such as enamel/dentin thickness and morphology of the external surface presented by the different dental groups, which interfere in the records of the pulse oximeter as demonstrated in a study by Silva *et al*. [63], and also reduce variations due to age, since a study by Estrela *et al*. [25] showed similar average level of oxygen saturation in premolars between individuals from 20 to 39 years old, but lower levels among the 40-44 years old age group, suggesting that older patients have smaller records of pulse oximeter.

With age, tooth color tends to become darker and more yellow [15, 29, 50]. A lumen diameter reduction in the dentinal tubules occurs in dentin as part of tooth aging through its progressive filling with mineral content [53]. The dentin chroma becomes more saturated and the overall tooth color value becomes lower. Additionally, the decrease in enamel thickness resulting from the use of teeth throughout life makes dentin dominate the color scale and contributes to the increase of yellowness on anterior teeth [66]. A study with a group of 180 adults and adolescents whose upper incisor color was evaluated with a spectrophotometer showed that each year of life, the average color changes more to yellow, reaching approximately 0.10 b* units and the average luminosity decreases in 0.22 L* units [50]. Optical changes, such as the dental crown's yellowness caused by aging and pulp obliteration, due to structural changes in enamel and dentin, seem to interfere with pulse oximeter recordings [25].

Measurements of oxygen saturation and evaluation by the spectrophotometer were performed in the middle third of the incisors. To pulse oximeter measurements, the middle third has been the place of choice for providing parallelism between the light emitting diode and the receiving photodiode, allowing light to reach the pulp chamber, and having less interference from the periodontium's blood circulation. The middle third of the tooth has also been described as the location that most represents the tooth color, as the incisal edge is often translucent and affected by its background, while the cervical color could be modified by diffraction of light coming from the gingiva [28, 49, 60].

The teeth color measurement can be performed in several ways, however, in this study, the CIE L*a*b* system was used by means of a spectrophotometer. The spectrophotometer has been shown to be a valuable and reliable tool to determine the dental crown's color in vitro and in vivo models [7, 42]. Spectrophotometers are not affected by light and environmental contrasts, and as a result, they are more accurate than the visual method, reproducibility being one of their great advantages [38, 42]. However, the equipment is complex and costly. Due to difficulties in measuring tooth color in vivo, positioning devices have been made to increase accuracy, and they have been shown to be acceptable for measuring tooth color changes longitudinally [2, 31, 47, 48, 56]. Moreover, for the analysis with the spectrophotometer, a silicone guide was used, which allowed the local standardization of the evaluations on the teeth before and after tooth whitening.

Several techniques and procedures for bleaching vital teeth are available, diversifying in type of bleaching agent, concentration, application time, product presentation and activating light [12, 16]. For this research, the combined bleaching technique was used, using 35% hydrogen peroxide in the office for 20 minutes, and at home, 10% carbamide peroxide for 16 days. These two techniques association has been recommended to promote an enhancement in tooth whitening, reducing the number of in-office whitening sessions and their adverse effects [16, 39, 40].

Pulse oximeters for dental use are not commercially available, therefore, in the present study, a medical oximeter was used, with an adapter used in several previous studies [12, 27]. Also, to knowledge detriment of pulse oximetry limitations,

inclusion criteria such as healthy patients, teeth with clinical diagnosis of healthy pulp, selection of a specific dental group, protocols to control patient movements, temperature and light variations at the time of measurement were adopted in the present study.

In this context, this research showed significant changes in pulse oximeter recordings after tooth whitening, however, the values remained within the saturation levels established for healthy maxillary central incisors in several studies [41], showing no clinical relevance. There was no correlation between pulse oximeter alterations and the dental crown's color change provided by bleaching procedures, suggesting that pulse oximeter recordings may be due to vascular alterations.

A study comparing pulse oximetry with direct pulp inspection showed that non-vital teeth were correctly identified with 100% sensitivity and 95% specificity. The effectiveness of pulse oximeter in assessing the teeth pulp condition with vital pulp has also been reported in several studies [8, 17, 46, 61, 62]. A systematic review [41] emphasizes that to increase the pulse oximeter accuracy it is necessary to develop a probe that adapts itself to the outline, shape and size of each tooth. Furthermore, it is necessary to carry out further studies on reflectance and light transmittance of pulse oximeter, to ensure this technology's usage for clinical diagnosis of pulp vitality accurately and reliably.

Conclusion

Changes in pulse oximeter recordings did not correlate with the dental crown's color change promoted by bleaching procedures.

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