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Use of colorimetry as a diagnostic tool for early detection of peri-implant diseases

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ABSTRACT

Introduction: The increasing aesthetic demand in dentistry and the limitations of visual colour assessment have encouraged the development of objective methods for evaluating dental and peri-implant tissues. Although colourimeters were originally designed for tooth shade matching, their application has recently expanded to peri-implant soft-tissue analysis, providing quantitative and reproducible measurements capable of detecting early inflammatory changes.

Objectives: This study aimed to determine whether colour analysis using a colourimeter is a valid diagnostic tool for the preliminary detection of peri-implant diseases by comparing colourimetric data with conventional clinical findings.

Materials and methods: A cross-sectional, descriptive, and experimental study was conducted on 63 dental implants. Peri-implant soft-tissue colour was recorded using a colourimeter based on CIELab parameters (L*, a*, b*). Each implant also underwent clinical evaluation including visual inspection, periodontal probing, and periapical radiography. Two measurement points were analysed: Point A, located 2 mm apical to the gingival margin, and Point B, positioned beyond the probing depth for each implant. Colourimetric values from both points were compared with the clinical diagnosis obtained for every implant.

Results: At Point B, peri-implant tissues showed lower luminosity (L*), higher redness (a*), and reduced b* values compared with Point A. Clinically, 48 implants presented peri-implantitis, 9 mucositis, and 6 were considered healthy. Diseased implants demonstrated darker and more reddish peri-implant tissues, revealing a clear correlation between colour alterations and inflammatory status.

1. Introduction

Dental implantology has undergone continuous technological and biological advances, improving implant performance and long-term maintenance.[1–3] Despite these high success rates, peri-implant diseases remain among the most frequent biological complications.[2] These conditions are defined as inflammatory pathological changes affecting the tissues surrounding a functional implant[2,4] and include peri-implant mucositis—characterised by reversible inflammation of the peri-implant mucosa without bone loss[2,4–7]—and peri-implantitis, a plaque-associated condition involving inflammatory mucosal changes and concomitant supporting bone loss.

Diagnosis of peri-implant disease relies on visual inspection for inflammation, suppuration or bleeding, periodontal probing to detect increased pocket depth, and radiographic evaluation to confirm bone loss.[8] Several factors influence the appearance of periodontal tissues, including their thickness and width, collectively referred to as the gingival biotype.[9–11] Thin tissues are more susceptible to recession and often respond less favourably to regenerative procedures.[9–11].

The chromatic characteristics of healthy gingiva depend on epithelial thickness, keratinisation and vascularisation, producing variations described in shades from pale pink to dark pink.[12–15] However, visual colour assessment has notable limitations due to lighting conditions, operator experience, age, and visual fatigue, reducing its diagnostic reliability.[8–10,16] As such, understanding baseline gingival colour is essential for recognising pathological tissue changes.

To overcome the subjectivity of visual assessment, electronic devices such as colourimeters and spectrophotometers have been introduced. These systems apply the CIE Lab colour space to quantify chromaticity using three parameters: L* (lightness), a* (green–red axis) and b* (blue–yellow axis).[13,14] These coordinates provide objective information on soft-tissue characteristics associated with perfusion, oxygenation

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and healing.[14] Colourimeters filter light into red, green and blue components and measure reflected wavelengths with high reproducibility, and their clinical use has increased notably in recent years.[17] Although developed for dental shade selection, colourimeters have been successfully used to assess peri-implant soft tissue colour, obtaining statistically significant findings.[18,19] Nevertheless, measurements may be affected by the irregular surface of the gingiva or variations in probe positioning, indicating a need for further research.[16,20,21]

Because peri-implant diseases continue to increase with the growing use of dental implants, the incorporation of innovative, objective diagnostic tools may contribute to earlier detection and improved clinical outcomes.

Therefore, the aim of this study was to determine whether colour measurement using a dental colourimeter may constitute a valid diagnostic tool for the preliminary detection of peri-implant diseases, and to evaluate whether peri-implant soft tissues affected by pathology exhibit a characteristic colour pattern. Additionally, colourimetric findings were compared with conventional clinical diagnostic parameters, including periodontal probing, visual inspection, and radiographic evaluation. It was hypothesised that objective colour analysis could allow early identification of peri-implant inflammatory changes.

2. Materials and methods

A cross-sectional, descriptive, and experimental study was conducted at a university dental hospital. The study protocol was approved by the local Research and Ethics Committee for Medicines and Health Products (code 2018-034), and written informed consent was obtained from all participants.

Several potential confounding variables were considered, including implant location, uncontrolled systemic disease, and gender. To obtain a homogeneous sample, inclusion criteria comprised patients with dental implants attending a **university dental hospital** for maintenance or treatment, individuals with a thick gingival biotype, adults aged 18 years or older, and those who signed informed consent. Exclusion criteria included gingival colour alterations from pigmentation or systemic diseases, thin gingival biotype, age under 18 years, and absence of consent. Gingival biotype was determined using the periodontal probe transparency method following established criteria, classifying gingiva as thin when the probe was visible through the margin and thick when it was not.[9,11,22]

A total of 63 dental implants were included as a preliminary sample. Peri-implant soft tissue colour was evaluated using a colourimeter (Rayplicker Borea, Limoges Cedex, France), which provides quantitative CIE Lab parameters. The L* coordinate measures brightness (0 = black, 100 = white), a* represents the green–red axis (negative values indicate green and positive values red), and b* represents the blue–yellow axis (negative values indicate blue and positive values yellow).[13,14,22–25] Colour difference (ΔE) was calculated as $\sqrt{((L_1\text{-}L_2)^2 + (a_1\text{-}a_2)^2 + (b_1\text{-}b_2)^2)}$. Various ΔE acceptability thresholds have been described, including 3.7 (Johnson & Kao), 3.1 (Sailer et al.), and 8.74 (Paniz et al.), the latter specifically for peri-implant soft tissues and therefore adopted in this study.[16,12,14,19,21–23,26–28]

Before each measurement, the colourimeter was automatically calibrated. To avoid bias from bleeding induced by probing, colourimetric evaluation was performed prior to clinical examination. All measurements were conducted by a single calibrated operator. The probe head was positioned parallel to the mucosal surface without pressure to prevent tissue ischemia. The obtained data were analysed with Rayplicker™ software (Version 1.0 for Mac), enabling pixel-by-pixel colour analysis. Two measurement points were recorded per implant: Point A, located 2 mm apical to the gingival margin, and Point B, located beyond the probing depth according to each implant. This allowed comparison between an area with bone support and one without. All data were tabulated for statistical comparison.

Clinical diagnosis was established through peri-implant probing, visual inspection, and periapical radiographs based on SEPA diagnostic criteria for peri-implant diseases (Table 1).[5] Mucositis was defined as bleeding and/or suppuration on probing, with or without increased probing depth, and absence of bone loss beyond initial remodeling.[2,4–7] Peri-implantitis was diagnosed when redness, swelling, bleeding and/or suppuration, increased pocket depth, and bone loss were present.[2,4–7] In the absence of previous records, peri-implantitis was diagnosed with probing depths ≥6 mm and bone levels ≥3 mm apical to the coronal implant margin.[5]

Probing was performed with a CP-11 probe at six sites per implant (V, MV, DV, P, MP, DP). Visual inspection assessed inflammation, redness, bleeding, and suppuration. Periapical radiographs were taken using the parallel technique with Bader positioning devices to minimise distortion, using recent radiographs when available to avoid unnecessary exposure. Both colourimetric and clinical diagnostic methods were applied to all patients for comparison.

For each patient, data collection sheets recorded all clinical and colourimetric parameters and potential risk variables. Statistical analysis was performed using SPSS software (IBM Corp., Armonk, NY, USA). Descriptive statistics were calculated, and comparisons between measurement points were performed using ANOVA. Pearson correlation analysis was applied to evaluate relationships between CIE Lab coordinates at the two points, and Mann–Whitney U tests were used to compare colourimetric differences between healthy and diseased peri-implant tissues. The selection of parametric or non-parametric tests was based on data distribution and sample characteristics, with non-parametric tests applied when normality assumptions were not met.

3. Results

A total of 63 dental implants from 36 patients treated at a university dental hospital were included. The sample consisted of 6 men (46.15 %) and 7 women (53.85 %), with a mean age of 59.5 years (range: 46–71). Four participants were regular smokers (30.77 %) and nine were non-smokers (69.23 %).

Clinically, 48 implants (76.2 %) showed bone loss and 45 (71.4 %) presented bleeding on probing. According to the diagnostic criteria of the Spanish Society of Periodontology and Osseointegration, 48 implants (76.19 %) were diagnosed with peri-implantitis, 9 (14.29 %) with mucositis, and 6 (9.52 %) were classified as healthy (Table 2).

In the colourimetric evaluation, Point A showed a mean L* value of 46.3 compared with 43.9 at Point B. For the a* parameter, mean values were 17.5 at Point A and 20.7 at Point B. The b* coordinate yielded mean values of 17.0 at Point A and 16.4 at Point B. Overall, the bone-supported area appeared darker (lower L*), redder (higher a*), and more bluish (lower b*) than the non–bone-supported region.

The mean ΔE between both points was 9.10 (range: 2.36–18.67), exceeding the ΔE soft-tissue perceptibility threshold of 8.74 in 10 of the 21 implants (47.61 %) (Table 3).

When stratified by clinical diagnosis, diseased implants (mucositis and peri-implantitis) showed darker (lower L*), redder (higher a*), and bluer (lower b*) peri-implant mucosa at Point A compared with healthy implants, except for the a* value in mucositis, which showed a greener tone (lower a*). At Point B, peri-implant tissues around diseased implants were darker (lower L*), greener (lower a*), and bluer (lower b*) than those around healthy implants (see Fig. 1).

Table 1
Diagnostic criteria for peri-implant diseases (2018 classification).

Condition	Diagnostic criteria
Mucositis	Bleeding/suppuration on probing, with or without increased probing depth, no bone loss beyond initial remodeling.
Peri-implantitis	Bleeding/suppuration on probing, increased probing depth, and bone loss ≥3 mm apical of the coronal implant margin.

Table 2
Mean CIELab values of peri-implant tissues.

Condition	L (luminosity)	a (green-red)	b (blue-yellow)
Healthy implants	46.3	17.5	17.0
Peri-implantitis/mucositis	43.9	20.7	16.4

Table 3
Reported ΔE thresholds for gingival/peri-implant tissues.

Author	ΔE threshold
Johnson & Kao	3.7 (dental threshold)
Sailer et al., 2014	3.1 (gingival tissues)
Paniz et al., 2014	8.74 (peri-implant tissues)

3.1. Statistical analysis

Only the L* parameter showed statistically significant differences between the two points ($p < 0.005$), with higher values at Point A (46.3) than at Point B (43.9). No significant differences were observed for a* or b* ($p > 0.005$). Fig. 2 illustrates these chromatic differences, showing that peri-implant mucosa at 2 mm from the gingival margin (Point A) appeared lighter, greener, and more yellowish than the bone-supported area (Point B). Non-parametric testing (Mann–Whitney U) indicated that, at Point A, the a* and b* distributions varied according to bleeding on probing.

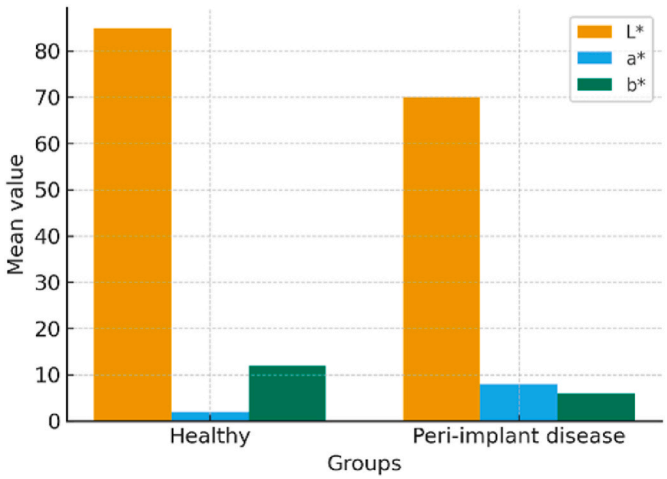

Fig. 2. Comparison of CIELab parameters (L*, a*, b*) between healthy implants and peri-implant disease sites.

4. Discussion

The present study aimed to determine whether colour measurement using a colourimeter could serve as a valid diagnostic tool for the preliminary detection of peri-implant diseases. For decades, subjective colour assessment has been the method of choice for most clinicians when selecting shades for dental restorations.[17] Numerous studies comparing subjective and objective colour evaluations have demonstrated that visual methods are prone to multiple sources of error, including lighting conditions, operator experience, age, visual fatigue, and patient-related factors.[17,28] The growing aesthetic demands in dentistry and the limitations of visual assessment have driven the development of objective colour determination techniques since the late 1970s.[28] Colourimeters and spectrophotometers overcome many of these limitations because they are unaffected by lighting variations and environmental contrasts, increasing accuracy by approximately 33 %. Paul et al. further reported a reproducibility rate of 83.3 % for such devices.[28]

Several authors have investigated whether the predictable performance of these instruments in dental shade matching can be extrapolated to gingival and peri-implant tissues. Studies comparing subjective and objective gingival colour evaluations concluded that spectrophotometric analysis using CIE Lab parameters is more accurate and reproducible than visual methods. Benic et al. found that only 60 % of peri-implant mucosal discolourations were perceptible at conversational distance,[8] while Varoni et al. similarly reported correct visual identification in only half of cases.[11] Despite this, visual evaluation remains widely used due to its simplicity and low cost.[16]

Although favourable outcomes have been reported for colourimetric and spectrophotometric analysis of soft tissues, these measurements are highly sensitive to pressure artefacts, and the irregular topography of peri-implant mucosa complicates consistent probe positioning.[14,17,21] Denissen et al. assessed gingival colour objectively and reported L* values between 72 and 78, a* between 12 and 23, and b* between 13 and 21 in healthy tissues.[13] Conversely, Gómez-Polo et al. observed wider interindividual variability.[14] Several additional authors comparing gingival and peri-implant tissues have shown that peri-implant mucosa generally appears darker (L ↓), greener (–a), and bluer (–b) than natural gingiva.[16,13,14,19–22,24,25]

In the present study, we sought to evaluate whether digital colour analysis could aid the preliminary diagnosis of peri-implant diseases by analysing chromatic changes at two measurement points—one with bone support and one without. Bone-supported areas showed darker (lower L*), redder (higher a*), and bluer (lower b*) values than non-supported regions. Although tissues at Point A often appeared more erythematous clinically, the deeper, non-keratinised mucosa at Point B may have allowed greater visibility of underlying vasculature, explaining the observed patterns.[15,20] When grouped by diagnosis, healthy implants exhibited lighter (higher L*), greener (lower a*), and more yellowish (higher b*) peri-implant mucosa compared with diseased

Fig. 1. Positioning of the colourimeter probe head parallel to the soft tissue, without applying pressure to avoid tissue ischemia.

implants, consistent with the absence of inflammation-induced redness.[5] Findings were also in line with the colour distribution described by Ho et al. across different racial groups.[12]

An important strength of this study is the combined assessment of objective colourimetric parameters and conventional clinical diagnostic criteria, allowing a more comprehensive evaluation of peri-implant tissue conditions. The use of a standardized colourimetric system based on CIE Lab parameters provides reproducible and operator-independent measurements, reducing the subjectivity inherent to visual assessment. In addition, the analysis of two defined measurement points within the same implant enabled an intra-implant comparison between bone-supported and non-supported regions, offering insight into chromatic behaviour that has been scarcely described in the literature. Finally, all measurements were performed by a single calibrated operator, minimizing methodological variability.

Healthy implants exhibited lighter, less reddish, and more yellowish peri-implant mucosa at 2 mm from the gingival margin compared with implants affected by peri-implantitis or mucositis. Statistically significant differences were found in L* values between bone-supported and non-supported regions. Although colourimeters show high accuracy for dental shade analysis, development of devices specifically designed for soft-tissue evaluation is needed. Colourimetric analysis may serve as a non-invasive tool for early detection of peri-implant diseases, reducing reliance on probing and radiographic exposure.

The study also presents limitations. The initial objective was to compare healthy gingiva with peri-implant tissues; however, most participants were edentulous or presented peri-implant pathology, preventing the inclusion of healthy gingival sites. Consequently, comparisons were limited to two measurement points within the same implant, one with bone support and one without, which restricts extrapolation to comparisons between healthy and diseased tissues. In addition, the sample size and study duration were limited. Furthermore, dental colourimeters are primarily designed for tooth shade assessment rather than soft-tissue analysis, and probe geometry may complicate positioning on peri-implant mucosa. Finally, the limited availability of literature on peri-implant soft-tissue colour constrained study design and interpretation.

5. Conclusions

Healthy implants exhibited lighter, less reddish, and more yellowish peri-implant mucosa at 2 mm from the gingival margin compared with implants affected by peri-implantitis or mucositis. Due to the small sample size, these findings cannot be generalised, and further studies with larger cohorts are required.

Statistically significant differences were observed in the L* coordinate between the two analysed points—one without bone support (Point A) and one with bone support (Point B). These differences highlight the potential of colourimetric evaluation to distinguish variations in peri-implant tissue condition.

Although dental colourimeters provide high accuracy for tooth shade determination, there is a need to develop instruments specifically adapted to soft-tissue analysis, with probe geometries and software designed for mucosal morphology.

Colourimetric assessment may constitute a useful, non-invasive tool for the early detection of peri-implant diseases, potentially reducing reliance on initial radiographic or probing examinations.

Patient's/guardian's consent

Not applicable.

Ethical clearance

Ethics approval was obtained (code 2018-034).

Author contribution

Sergi Torne Duran: Conceptualization, Data Curation, Methodology, Software, Investigation, Visualization, Writing – Original Draft, Supervision, Validation, Writing – Review & Editing.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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