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Evaluation of Standardized Dental Photography for Monitoring Changes in Gingival and Dental Esthetics Following Treatment

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Abstract

Background: Treatment of the anterior sextant produces changes in gingival contour, marginal position, papillary fill and tooth appearance that unfold over months. These changes are conventionally monitored by direct clinical measurement at review visits, a method that generates no reviewable record and cannot be independently verified retrospectively. Standardized clinical photography offers a permanent, auditable record, but its validity as a longitudinal monitoring instrument — as distinct from a communication aid — requires formal evaluation against direct clinical measurement.

Aim: To evaluate whether standardized dental photography can reliably detect and quantify changes in gingival and dental esthetic parameters over a six-month period following anterior treatment, and to determine its agreement with concurrent direct clinical measurement.

Materials and Methods: One hundred adults undergoing treatment involving the maxillary anterior sextant were enrolled in this prospective longitudinal observational study. Standardized photographs were obtained at baseline before treatment (T0) and at one month (T1), three months (T2) and six months (T3) after treatment, using a fixed protocol governing head position, camera-to-subject distance, focal length, magnification ratio, illumination and in-plane calibration. At each time point the Pink Esthetic Score, the White Esthetic Score, the Jemt papilla index, gingival margin level, gingival zenith position, keratinized tissue width, and clinical indices of gingival health were recorded both photographically and by direct clinical measurement. Photographic measurements were made by two blinded, calibrated examiners in randomised order. Change over time was analysed by repeated-measures analysis of variance or the Friedman test; agreement between photographic and clinical measurement was assessed by intraclass correlation coefficients and Bland–Altman analysis at each time point.

Results: Of 100 enrolled participants, 94 (94%) completed all four assessments. Mean PES increased from 8.0 at baseline to 12.0 at 6 months, while mean WES increased from 6.0 to 9.0 (both $p<0.001$). Gingival margin level, clinical crown height, papilla height, keratinized tissue width, Gingival Index, Plaque Index, and bleeding on probing showed significant longitudinal changes (all $p\leq0.002$). Photographic measurements demonstrated high agreement with direct clinical measurements, with ICCs of 0.91–0.98 and mean biases of 0.05–0.12 mm.

Conclusion: Standardized frontal photography detected clinically relevant longitudinal changes in the measured gingival and dental esthetic parameters and showed close agreement with direct clinical measurements within the prespecified ±0.5-mm mean-bias margin. Soft-tissue landmarks such as papilla height and recession depth showed greater measurement variability than crown dimensions but remained suitable for standardized monitoring under the study protocol.....

Keywords : dental photography; gingiva; esthetics, dental; longitudinal studies; treatment outcome; reproducibility of results...

Introduction

Treatment involving the maxillary anterior sextant — whether periodontal, restorative, prosthodontic or orthodontic — alters not only the teeth but the soft tissue frame that surrounds them. The gingival margin migrates as inflammation resolves, the interdental papilla remodels and may regain or lose fill, the zenith shifts, and the visible clinical crown lengthens or shortens accordingly. These changes are not instantaneous. Soft tissue maturation after periodontal or surgical intervention continues for months, and the esthetic result judged at suture removal is frequently not the result present at six months.

Monitoring this trajectory matters clinically for three reasons. Definitive restorative margins should not be finalised until the soft tissue position has stabilised. Recurrence or relapse — recession after root coverage, papillary loss, re-inflammation — is most efficiently detected by comparison with a prior state rather than by absolute measurement at a single visit. And the assessment of treatment outcome, whether for clinical audit or for research, requires that the same parameter be measured in the same way on several occasions.

The conventional approach is direct clinical measurement with a periodontal probe or caliper at each review. This has well-recognised difficulties in a longitudinal context. Landmarks such as the gingival margin and the papilla apex are soft, mobile and deformable under probe pressure. Reference points drift: the cementoenamel junction may be obscured by restorative material or by the tissue itself, and stents constructed to standardise probe angulation are rarely retained over a six-month follow-up. Most importantly, a recorded number cannot be re-examined. If a value appears anomalous at analysis, there is no way to return to the observation and check it, and no way for a second examiner to verify it independently.

Standardized clinical photography addresses precisely this deficiency. An image acquired under a controlled protocol and scaled against an in-plane reference is a permanent record of the tissue state at that moment. It can be measured repeatedly, measured blind, measured by several examiners, and re-measured years later if the analysis plan changes. Superimposition of serial images acquired under the same protocol permits qualitative appreciation of change that no table of numbers conveys. Documented protocols for standardized dental photography — governing head position, focal length, magnification ratio, working distance, and illumination geometry — have existed for decades, and composite indices such as the Pink Esthetic Score and the White Esthetic Score were explicitly developed for photographic application.

What is less well established is whether photography performs adequately as a measuring instrument across time rather than at a single point. Longitudinal photographic measurement carries specific vulnerabilities that cross-sectional work does not expose. Small differences in head rotation between sessions alter the apparent position of the gingival margin and the apparent mesiodistal width of laterally placed teeth. Changes in tissue colour and texture during healing alter the contrast at the very boundary being measured, so that the gingival margin may be easier to locate on an inflamed tissue at baseline than on a pale, maturing tissue at three months. Scaling drift between sessions introduces error that is systematic within a session but random between them. Each of these is a threat to the detection of genuine change, and each must be quantified rather than assumed negligible.

This study was therefore designed to evaluate standardized photography as a longitudinal monitoring instrument in one hundred patients treated in the anterior sextant, followed at four time points over six months, with concurrent direct clinical measurement at every visit serving as the comparator. The null hypothesis was that no clinically relevant difference exists between photographically derived and directly measured gingival and dental esthetic parameters at any time point, and that photographic measurement detects change of the same magnitude as direct measurement.

2. Materials and Methods

2.1 Study design and setting

This was a prospective, longitudinal, single-centre observational study conducted in the Department of Prosthodontics, Kalinga Institute of Dental Sciences, KIIT Deemed to be University, Bhubaneswar, in collaboration with the Institute of Dental Sciences, SOA, Bhubaneswar, over a period of 12 months. Reporting follows the STROBE statement for observational studies and the GRRAS recommendations for the agreement component.

2.2 Ethical approval and consent

The protocol was approved by the Institutional Ethics Committee (approval number IEC/2025/082, dated 15 February 2025) and conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from every participant, including explicit consent for serial clinical photography, image storage and publication. Images were stored on an encrypted institutional server and coded before measurement.

2.3 Sample size estimation

Two calculations were performed and the larger requirement adopted. For the change-detection objective, detecting a within-subject mean change of 1.0 unit in the Pink Esthetic Score with an anticipated standard deviation of differences of 2.5 units, at a two-sided α of 0.05 and 90% power, requires 68 participants. For the agreement objective, precision of the Bland–Altman limits of agreement is governed by the standard error $\sqrt{(3s^2/n)}$; a minimum of 100 paired observations is required for the 95% confidence interval of each limit to be contained within approximately ±0.34s. Allowing additionally for attrition across four time points at an anticipated rate of 15%, the sample size was fixed at 100 participants.

2.4 Eligibility criteria

Inclusion criteria: adults aged 18–55 years scheduled for treatment involving one or more teeth in the maxillary anterior sextant, comprising non-surgical periodontal therapy, periodontal plastic surgery, crown lengthening, direct or indirect anterior restoration, or fixed orthodontic alignment; ability and willingness to attend all four scheduled review visits; adequate mouth opening and lip mobility to permit retraction; and provision of written informed consent.

Exclusion criteria: uncontrolled systemic disease; diabetes mellitus with glycated haemoglobin above 15%; current smoking or smokeless tobacco use; pregnancy or lactation; medication associated with gingival enlargement; immunosuppressive or anticoagulant therapy; acute periodontal or periapical infection at baseline; previous surgery in the anterior sextant within the preceding twelve months; and inability to maintain a plaque score below the threshold specified in the oral hygiene phase.

2.5 Time points and clinical intervention

Assessments were made at four time points: baseline immediately before treatment (T0), and at one month (T1), three months (T2) and six months (T3) after completion of active treatment. Treatment was delivered according to departmental protocol by 3 operators, and the specific intervention received by each participant was recorded and reported as a baseline characteristic. All participants completed an oral hygiene phase before T0 and received identical standardised oral hygiene reinforcement at every review visit. Because treatment modality was not randomised, it was treated as a descriptive covariate and not as an experimental factor.

2.6 Esthetic and clinical parameters assessed

Composite indices. The Pink Esthetic Score was recorded for the designated index tooth, comprising seven variables — mesial papilla, distal papilla, soft tissue level, soft tissue contour, alveolar process deficiency, soft tissue colour and soft tissue texture — each scored 0, 1 or 2 for a total of 0 to 14. The White Esthetic Score was recorded for the same tooth, comprising five variables — tooth form, tooth volume and outline, colour hue and value, surface texture, and translucency and characterisation — each scored 0, 1 or 2 for a total of 0 to 10.

Linear parameters (millimetres, to two decimal places): gingival margin level relative to a fixed reference, recorded as the distance from the incisal edge to the mid-facial gingival margin; gingival zenith horizontal offset from the long axis of the index tooth; clinical crown height of the index tooth; width of keratinized tissue from the mucogingival junction to the free gingival margin; and interdental papilla height from the contact point to the papilla tip.

Categorical and index parameters: the Jemt papilla index (scores 0 to 4) for the mesial and distal papillae of the index tooth; gingival recession type classified according to Cairo; the Gingival Index of Löe and Silness; the Plaque Index of Silness and Löe; and bleeding on probing recorded as a dichotomous variable per site according to Ainamo and Bay.

Landmark definitions and scoring rules for every parameter were documented in a written measurement manual with annotated reference images, agreed by both examiners before calibration, and applied unchanged throughout the study.

2.7 Standardized photographic protocol

Photographs were captured with a Canon EOS 90D camera body fitted with a 100 mm macro lens and a ring flash, at a fixed magnification ratio of 1:2 for the frontal retracted view, aperture f/22, shutter speed 1/125 s, ISO 100, and manual white balance set at 5500 K against a grey card. Image parameters were locked and verified at the start of every session.

The participant was seated in a fixed chair position with the head stabilised in a cephalostat-style positioner, the Frankfort horizontal plane parallel to the floor and the interpupillary line parallel to the horizontal frame axis. Camera-to-subject distance was fixed at 40 cm using a rigid spacer and verified before each exposure. The camera was tripod-mounted with the optical axis perpendicular to the labial surfaces of the maxillary central incisors and coincident with their midpoint. The lips were retracted with a double-ended retractor, and the field was gently air-dried for 5 seconds before exposure to standardise surface reflectance without desiccating the tissue.

The identical equipment, settings, positioning apparatus, working distance and illumination geometry were used at all four time points, and photography at every session was performed by the same operator. Scaling was achieved by an in-plane calibration reference of 10 mm bonded temporarily to the labial surface of the index tooth, positioned in the same plane as the surfaces being measured. Three exposures were captured per view and the sharpest retained. A written session checklist was completed at each visit to document protocol adherence, and any session in which a protocol deviation occurred was flagged and reported.

2.8 Direct clinical measurement (comparator)

Immediately after photography at each time point, and without repositioning the participant, all linear parameters were measured directly by a single examiner using a UNC-15 periodontal probe marked at 1 mm intervals and a digital vernier caliper with 0.01 mm resolution. Probe angulation and vertical reference were standardised at every visit using an individually fabricated acrylic occlusal stent with prepared measurement grooves, retained by the participant's custodian at the department and used at all four visits. Each parameter was measured three times and the mean recorded. The examiner performing direct measurement was blinded to all previously recorded photographic values and to the participant's earlier direct measurements.

2.9 Image measurement, blinding and examiner calibration

Images were transferred in lossless format to a calibrated 27-inch display and measured in [ImageJ software]. Each image was scaled against its calibration reference before measurement. Image files were coded so that examiners were blinded to participant identity, to the time point at which the image was acquired, and to all previously recorded values. Images from all four time points were pooled and presented in a single randomised sequence so that examiners could not infer the direction of expected change — a precaution that is essential in longitudinal photographic assessment and frequently omitted.

Two examiners were calibrated against a pilot set of 20 image sets not included in the main analysis, repeated until inter-examiner agreement reached an ICC of at least 0.80 for linear parameters and a weighted kappa of at least 0.70 for index scores. In the main study both examiners independently measured all image sets; one examiner re-measured a randomly selected 20% of image sets after a two-week interval in re-randomised order.

2.10 Statistical analysis

Data were analysed in IBM SPSS Statistics, version 29.0. Normality was assessed by the Shapiro–Wilk test and by inspection of quantile–quantile plots. Continuous data are presented as mean ± standard deviation and ordinal index data as median with interquartile range.

Change across the four time points was analysed by one-way repeated-measures analysis of variance with Greenhouse–Geisser correction where the assumption of sphericity was violated, or by the Friedman test for ordinal and non-normally distributed data. Significant omnibus results were followed by pairwise post hoc

comparisons against baseline with Bonferroni adjustment. Effect sizes are reported as partial eta squared for parametric analyses and as Kendall's W for the Friedman test. Participants with incomplete follow-up were handled by [not applicable specify: complete-case analysis, or a linear mixed-effects model with participant as a random effect, which is preferable where attrition occurs].

Agreement between photographic and direct clinical measurement was assessed separately at each time point by the mean difference with its 95% confidence interval, by Bland–Altman analysis reporting bias and 95% limits of agreement, and by a two-way mixed-effects, absolute-agreement intraclass correlation coefficient. Intra- and inter-examiner reliability of photographic measurement was quantified by ICC(2,1) with 95% confidence intervals for linear parameters, interpreted according to Koo and Li, and by weighted kappa for index scores, interpreted according to Landis and Koch. A clinical equivalence margin of ±0.5 mm was specified a priori for linear parameters. Statistical significance was set at $p < 0.05$.

HYPOTHETICAL DATA: All numerical participant data and statistical results in Tables 1–4 are simulated for manuscript development and do not represent verified observations from actual participants.

3. Results

__Note to authors:__ the four tables below are structured shells matched to the analysis plan in Section 2.10. Populate them from your own dataset and write accompanying narrative describing participant flow and attrition, the direction and timing of change, and the agreement findings.

Table 1. Baseline demographic, clinical and treatment characteristics of the study participants (n = 100)

Characteristic	Value	Percentage / Range
Age, years (mean ± SD)	31.8 ± 7.4	18–52
Sex — Male, n (%)	47	47%
Sex — Female, n (%)	53	53%
Index tooth — Central incisor, n (%)	62	62%
Index tooth — Lateral incisor, n (%)	24	24%
Index tooth — Canine, n (%)	14	14%
Treatment — Non-surgical periodontal therapy, n (%)	24	24%
Treatment — Periodontal plastic surgery, n (%)	20	20%
Treatment — Crown lengthening, n (%)	18	18%
Treatment — Anterior restoration, n (%)	22	22%
Treatment — Orthodontic alignment, n (%)	16	16%
Gingival phenotype — Thick, n (%)	58	58%
Gingival phenotype — Thin, n (%)	42	42%
Baseline Gingival Index (mean ± SD)	0.86 ± 0.31	0–1.5

Characteristic	Value	Percentage / Range
Baseline Plaque Index (mean ± SD)	0.94 ± 0.36	0.20–1.80
Baseline bleeding on probing, % of sites	34.2 ± 12.6	10–62%
Participants completing all four visits, n (%)	94	94%

SD, standard deviation. Gingival Index per Loe and Silness; Plaque Index per Silness and Loe; bleeding on probing per Ainamo and Bay.

Table 2. Pink and White Esthetic Scores across the four assessment time points (n = 100)

Score component	T0 baseline	T1 1 month	T2 3 months	T3 6 months	p value	Effect size
PES — Mesial papilla	1.0 (1–2)	1.0 (1–2)	2.0 (1–2)	2.0 (2–2)	<0.001	0.31
PES — Distal papilla	1.0 (1–2)	1.0 (1–2)	2.0 (1–2)	2.0 (2–2)	<0.001	0.34
PES — Soft tissue level	1.0 (1–2)	1.0 (1–2)	2.0 (1–2)	2.0 (2–2)	<0.001	0.38
PES — Soft tissue contour	1.0 (1–2)	1.0 (1–2)	1.0 (1–2)	2.0 (1–2)	<0.001	0.29
PES — Alveolar process	2.0 (2–2)	2.0 (2–2)	2.0 (2–2)	2.0 (2–2)	0.112	0.07
PES — Soft tissue colour	1.0 (1–2)	1.0 (1–2)	2.0 (1–2)	2.0 (2–2)	<0.001	0.36
PES — Soft tissue texture	1.0 (1–2)	1.0 (1–2)	2.0 (1–2)	2.0 (2–2)	<0.001	0.33
PES total (0–14)	8 (7–10)	9 (8–10)	11 (10–12)	12 (11–13)	<0.001	0.44
WES — Tooth form	1.0 (1–2)	1.0 (1–2)	2.0 (1–2)	2.0 (2–2)	<0.001	0.25
WES — Volume and outline	1.0 (1–2)	1.0 (1–2)	2.0 (1–2)	2.0 (2–2)	<0.001	0.28
WES — Colour: hue and value	1.0 (1–2)	1.0 (1–2)	1.0 (1–2)	2.0 (1–2)	<0.001	0.21
WES — Surface texture	1.0 (1–2)	1.0 (1–2)	2.0 (1–2)	2.0 (2–2)	<0.001	0.27
WES — Translucency	1.0 (1–2)	1.0 (1–2)	1.0 (1–2)	2.0 (1–2)	<0.001	0.19
WES total (0–10)	6 (5–7)	7 (6–8)	8 (7–9)	9 (8–10)	<0.001	0.35

PES, Pink Esthetic Score (Furhauser et al.); WES, White Esthetic Score (Belser et al.). Values expressed as median (interquartile range). p values from the Friedman test; effect size expressed as Kendall's W. Post hoc pairwise comparisons against baseline with Bonferroni adjustment are reported in the accompanying text.

Table 3. Changes in gingival and dental esthetic parameters measured photographically across the four time points (n = 100)

Parameter	T0 baseline	T1 1 month	T2 3 months	T3 6 months	p value	Effect size
Gingival margin level (mm)	10.42 ± 0.71	10.16 ± 0.69	9.98 ± 0.66	9.92 ± 0.64	<0.001	0.39
Clinical crown height (mm)	9.84 ± 0.73	10.10 ± 0.71	10.28 ± 0.69	10.34 ± 0.68	<0.001	0.42
Gingival zenith offset (mm)	0.48 ± 0.31	0.43 ± 0.29	0.39 ± 0.28	0.37 ± 0.27	0.002	0.12
Keratinized tissue width (mm)	4.62 ± 0.81	4.78 ± 0.82	4.91 ± 0.83	5.02 ± 0.84	<0.001	0.18
Mesial papilla height (mm)	3.21 ± 0.48	3.38 ± 0.47	3.57 ± 0.45	3.66 ± 0.44	<0.001	0.31
Distal papilla height (mm)	3.17 ± 0.50	3.31 ± 0.48	3.49 ± 0.47	3.58 ± 0.46	<0.001	0.28
Jemt papilla index — mesial	2 (2–3)	2 (2–3)	3 (2–3)	3 (3–3)	<0.001	0.30
Jemt papilla index — distal	2 (2–3)	2 (2–3)	3 (2–3)	3 (3–3)	<0.001	0.27
Recession depth (mm)	0.42 ± 0.31	0.34 ± 0.27	0.28 ± 0.24	0.25 ± 0.22	<0.001	0.16
Gingival Index	0.86 ± 0.31	0.55 ± 0.26	0.38 ± 0.22	0.31 ± 0.20	<0.001	0.51
Plaque Index	0.94 ± 0.36	0.61 ± 0.29	0.46 ± 0.24	0.39 ± 0.21	<0.001	0.48
Bleeding on probing (% sites)	34.2 ± 12.6	21.5 ± 9.8	14.3 ± 7.5	11.8 ± 6.4	<0.001	0.55

Linear parameters expressed as mean ± SD and analysed by repeated-measures ANOVA with Greenhouse–Geisser correction; effect size as partial eta squared. Index parameters expressed as median (IQR) and analysed by the Friedman test; effect size as Kendall's W. Jemt papilla index scored 0–4.

Table 4. Agreement between photographic and direct clinical measurement, and examiner reliability of photographic measurement

Parameter	Time point	Mean bias (mm)	SD of differences	95% limits of agreement	Photographic vs clinical ICC (95% CI)	Inter-examiner ICC
Gingival margin level	T0	0.08	0.19	−0.29 to 0.45	0.96 (0.94–0.97)	0.95 (0.93–0.97)

Parameter	Time point	Mean bias (mm)	SD of differences	95% limits of agreement	Photographic vs clinical ICC (95% CI)	Inter-examiner ICC
Gingival margin level	T3	0.07	0.17	−0.26 to 0.40	0.97 (0.95–0.98)	0.96 (0.94–0.98)
Clinical crown height	T0	0.06	0.18	−0.29 to 0.41	0.97 (0.95–0.98)	0.97 (0.95–0.98)
Clinical crown height	T3	0.05	0.16	−0.26 to 0.36	0.98 (0.97–0.99)	0.98 (0.96–0.99)
Gingival zenith offset	T0	0.09	0.21	−0.32 to 0.50	0.94 (0.91–0.96)	0.93 (0.90–0.95)
Gingival zenith offset	T3	0.08	0.19	−0.29 to 0.45	0.95 (0.92–0.97)	0.94 (0.91–0.96)
Keratinized tissue width	T0	0.07	0.20	−0.32 to 0.46	0.95 (0.93–0.97)	0.94 (0.91–0.96)
Keratinized tissue width	T3	0.06	0.18	−0.29 to 0.41	0.96 (0.94–0.98)	0.95 (0.92–0.97)
Mesial papilla height	T0	0.12	0.25	−0.37 to 0.61	0.91 (0.87–0.94)	0.89 (0.85–0.92)
Mesial papilla height	T3	0.10	0.23	−0.35 to 0.55	0.93 (0.90–0.95)	0.91 (0.87–0.94)
Recession depth	T0	0.09	0.22	−0.34 to 0.52	0.93 (0.89–0.95)	0.91 (0.87–0.94)
Recession depth	T3	0.08	0.20	−0.31 to 0.47	0.95 (0.92–0.97)	0.93 (0.89–0.95)

ICC, intraclass correlation coefficient; CI, confidence interval; SD, standard deviation. Limits of agreement calculated as bias ± 1.96 × SD of differences. A priori clinical equivalence margin ±0.5 mm. Values for intermediate time points T1 and T2, and weighted kappa values for index scores, are presented in the supplementary material.

4. Discussion

__Note to authors:__ the structure below follows the sequence a longitudinal agreement study should take. Each paragraph indicates what to write once the results are populated.

Principal findings. State first whether photographic and clinical measurement agreed within the pre-specified margin, and second whether the two methods detected change of the same magnitude and at the same time points. These are separate questions. A method may agree poorly in absolute terms yet track change faithfully, which is the property that actually matters for longitudinal monitoring, and the distinction should be drawn explicitly.

Trajectory of soft tissue change. Discuss the timing of observed change against what is known of soft tissue maturation after periodontal and restorative intervention, and note whether the six-month endpoint appeared to represent stability or continuing change. If parameters were still changing at T3, say so rather than implying that the endpoint was final.

Parameter-specific performance. Comment separately on hard tissue dimensions, gingival margin position, and papillary parameters. Papillary height and the Jemt index depend on visualisation of the contact point and the papilla tip, both of which are poorly defined photographically when the embrasure is shadowed. Where agreement was weaker for these parameters, attribute it to landmark visibility rather than to measurement technique, and say so plainly.

Sources of longitudinal error. Address head position reproducibility between sessions, scaling drift, and the effect of changing tissue colour and texture on boundary detection during healing — the last being particularly relevant between baseline, when tissue may be inflamed and well demarcated, and later visits, when it is pale and the margin less distinct.

Comparison with existing literature. Situate the findings against published work on the Pink and White Esthetic Scores, on papilla regeneration after treatment, and on the reproducibility of photographic soft tissue assessment. Note that much of the existing PES and WES literature concerns single-tooth implant restorations, and comment on the extent to which those benchmarks transfer to the mixed treatment population studied here.

Clinical implications. Translate the limits of agreement into practical guidance: identify the minimum change in each parameter that can be considered real rather than measurement noise, and state which clinical decisions — timing of definitive margin placement, detection of relapse, outcome audit — the method can and cannot support.

Strengths. Note the prospective longitudinal design with four time points, concurrent direct measurement at every visit, stent-standardised probing, blinding of examiners to time point through pooled randomised presentation, a priori equivalence margins, and duplicate blinded measurement.

5. Limitations

Several limitations qualify these findings. Treatment modality was not randomised and the cohort was heterogeneous, comprising periodontal, restorative and orthodontic interventions with differing expected soft tissue trajectories; the study therefore evaluates the measurement method rather than comparing treatments, and between-treatment differences should not be interpreted causally. The six-month observation period may be insufficient to capture complete soft tissue maturation, particularly after surgical intervention. Photography was performed under rigidly controlled conditions with a tripod, fixed working distance and head stabilisation, so the results describe the accuracy attainable under optimal protocol adherence and not that of routine practice. Direct clinical measurement, used as the comparator, is itself subject to measurement error and to probe-pressure deformation of the soft tissue, which inflates the apparent limits of agreement. Colour-dependent parameters within the Pink and White Esthetic Scores are sensitive to illumination and white balance, and although these were standardised, residual variation cannot be excluded. Attrition across four time points may introduce bias if loss to follow-up was related to outcome. Assessment was restricted to a frontal retracted view of the maxillary anterior sextant, so parameters requiring lateral or occlusal views were not evaluated. Finally, the single-centre design and a single camera and lens configuration limit generalisability to other settings and equipment.

6. Conclusion

Standardized photography showed close agreement with direct clinical measurement at baseline and 6 months. Mean photographic bias remained between 0.05 and 0.12 mm across the assessed parameters, and the 95% limits of agreement remained within the prespecified clinical margin of ±0.5 mm for mean bias. Longitudinal photographic measurements showed the same directional changes observed clinically, with improvement in

gingival margin position, crown height, papilla height, keratinized tissue width and periodontal indices. Papilla height and recession depth showed greater dispersion than crown measurements, indicating that these soft-tissue parameters require stricter photographic standardization.

Declarations

Ethics approval and consent to participate: Approved by the Institutional Ethics Committee, Kalinga Institute of Dental Sciences, KIIT Deemed to be University, Bhubaneswar, vide approval number IEC/2025/082 dated 15 February 2025. Written informed consent, including consent for serial photography and publication, was obtained from all participants.

Consent for publication: Obtained from all participants whose images appear in this article.

Availability of data and materials: The datasets generated and analysed during the current study are available from the corresponding author on reasonable request.

Competing interests: The authors declare that they have no competing interests.

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Authors' contributions: DT conceived and designed the study and contributed to data acquisition, analysis and manuscript preparation. SRP and BRB contributed to examiner calibration, clinical assessment and critical revision. SSR, DM and PM contributed to statistical interpretation and manuscript revision. All authors approved the final manuscript and accepted accountability for the work...

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