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Comparative Assessment of Periodontal Soft Tissue Thickness Using a Novel Radiopaque CBCT Protocol Versus Conventional Transgingival Probing in a Regional Cohort: Clinical, Technological, and Interdisciplinary Implications

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ABSTRACT

Background & Objectives: The spatial orientation and vertical thickness of periodontal soft tissues act as a critical biological barrier governing esthetic predictability and structural survival in periodontics, orthodontics, and implant dentistry. While conventional transgingival probing (TGP) under local anesthesia has served as the historical baseline, it is inherently invasive, operator-dependent, and prone to fluid-induced tissue deformation. This prospective, comparative clinico-radiographic study evaluates the diagnostic accuracy, reliability, and mathematical agreement of a novel non-invasive Cone-Beam Computed Tomography (CBCT) protocol utilizing a standardized radiopaque adhesive marker against conventional TGP in a North Gujarat cohort.

Methods: Sixty systemically healthy subjects (42 males, 18 females; mean age 34.42 ± 9.05 years) requiring CBCT scans were recruited. A standardized template featuring a 3-mm punched window positioned 3 mm apical to the marginal gingiva mid-buccally was affixed to the maxillary anterior teeth. A radiopaque 4-META/MMA-TBB adhesive cement marker was placed to establish an identical reference landmark. Digital cross-sectional measurements were recorded via high-resolution CBCT software (CS 9600 3D CMOS Sensor, voxel size ≥ 75 μm) and compared against direct bone sounding performed perpendicularly through the cement center using a UNC-15 probe with a rubber stopper and digital caliper (0.1 mm precision). Data were analyzed using descriptive statistics and the independent Student's t-test ($\alpha = 0.05$).

Results: The mean soft tissue thickness recorded via conventional TGP was 1.95 ± 0.27 mm (range: 1.50–2.40 mm), while the corresponding mean thickness measured via digital CBCT was 1.93 ± 0.31 mm (range: 1.40–2.60 mm). The absolute

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mean difference between modalities was 0.02 mm. Statistical analysis confirmed no significant difference between the two techniques ($t = 0.377$, $p > 0.05$, $p = 0.707$). Both modalities demonstrated exceptional consistency and phenotypic clustering around the 1.9–2.0 mm structural threshold.

Conclusions & Healthcare Delivery Impact: Cone-Beam Computed Tomography combined with a standardized radiopaque marker protocol provides an exceptionally accurate, reproducible, and non-invasive alternative to invasive bone sounding. Transitioning to non-invasive digital phenotyping eliminates procedural patient trauma, optimizes pre-surgical risk stratification, and provides healthcare providers with a validated technology to enhance clinical workflow predictability and service quality...

Keywords: Cone-Beam Computed Tomography; Transgingival Probing; Periodontal Phenotype; Soft Tissue Thickness; Non-Invasive Diagnostics; Dental Technology Adoption; Health Service Quality.

INTRODUCTION

The structural integrity, dimensional volume, and spatial orientation of periodontal soft tissues play a definitive biological role in dictating the long-term clinical and esthetic outcomes of contemporary dental therapeutic interventions [1, 2]. Historically conceptualized under broader classifications such as "gingival biotype," modern dental paradigms recognize this anatomical variable as the *periodontal phenotype* [3]. The periodontal phenotype integrates two critical morphological components: the gingival phenotype (encompassing vertical gingival thickness [GT] and keratinized tissue width [KTW]) and the underlying facial alveolar bone morphotype [3, 4].

Among these anatomical parameters, soft tissue thickness (STT) functions as an essential defensive barrier that governs micro-vascularity, inflammatory propagation, and post-surgical tissue remodeling [2, 5]. Clinicians routinely evaluate baseline STT prior to executing periodontal plastic surgery (e.g., subepithelial connective tissue grafting for root coverage), orthodontic tooth translation through narrow cortical plates, and immediate or delayed endosseous dental implant placement [2, 4]. An inadequate, thin tissue profile (< 2.0 mm) leaves patients highly susceptible to severe mucosal recession, unesthetic restorative margins, and early crestal bone resorption triggered by the physiological establishment of the supracrestal tissue attachment (formerly biological width) [3, 6, 28].

Despite its paramount clinical importance, standardizing the objective measurement of oral soft tissues in vivo remains a major challenge. Human gingiva is viscoelastic, compressible, and lacks rigid coronal reference points [6]. Traditionally, clinical evaluation has relied on either qualitative methods (such as the probe transparency method, which merely dichotomizes tissues into "thick" or "thin" categories without providing discrete millimetric values) or invasive quantitative methods [2, 5].

Transgingival probing (TGP)—also known as bone sounding—has long served as the conventional quantitative benchmark [1, 5]. TGP involves penetrating the anesthetized mucosal matrix with an endodontic file or periodontal probe until the underlying alveolar bone is encountered [1, 4]. However, TGP is inherently invasive, operator-dependent, susceptible to probe angulation errors, and introduces systematic manual rounding errors (up to 0.5 mm) [6, 7]. Furthermore, the required local anesthetic infiltration introduces fluid volumes that can artificially distort local tissue thickness [7].

To overcome these invasive limitations, advanced 3D digital imaging through Cone-Beam Computed Tomography (CBCT) has emerged as an indispensable modality [4, 8]. While conventional CBCT is optimized for mineralized tissues and suffers from low soft-tissue contrast resolution due to scatter radiation, contemporary clinical protocols incorporating lip-cheek retractors and localized radiopaque contrast markers (such as 4-META/ MMA-TBB adhesive cements) allow precise boundary segmentation of the overlying mucosa [4, 6, 16].

Moreover, periodontal phenotypes are significantly influenced by regional genetics, dietary habits, and anthropometric characteristics [3]. The vast majority of published literature on gingival thickness originates from Western or East Asian cohorts, leaving a distinct knowledge gap regarding semi-urban and rural populations in North Gujarat, India. This study was conducted to evaluate the diagnostic accuracy, reliability, and degree of agreement of a novel radiopaque marker-assisted CBCT protocol compared with conventional transgingival probing in a standardized North Gujarat population.

MATERIALS AND METHODS

Study Design and Ethical Considerations

This prospective, comparative, clinico-radiographic study was carried out in the Department of Periodontology, Narsinhbhai Patel Dental College & Hospital, Sankalchand Patel University (SPU), Visnagar, Gujarat, India. The study protocol was reviewed and formally approved by the Institutional Ethics Committee (IEC). Written informed consent was obtained from all participating individuals prior to enrollment, following the ethical principles outlined in the

Declaration of Helsinki.

Patient Selection and Eligibility Criteria

A total of 60 systemically healthy subjects (comprising 42 males and 18 females, aged 18 to 50 years) who presented to the outpatient department and required CBCT diagnostic imaging for interdisciplinary treatment planning were enrolled based on strict criteria:

Inclusion Criteria: (1) Age 18–50 years; (2) Systemically healthy status with intact periodontium and clinical gingival health; (3) Requirement of CBCT scan for therapeutic/diagnostic purposes; (4) Fully signed informed consent.

Exclusion Criteria: (1) Age > 50 years; (2) Presence of crowns, restorations, or cervical abrasions extending to/beyond the cemento-enamel junction (CEJ); (3) Systemic conditions affecting periodontal status (e.g., uncontrolled diabetes mellitus, immunosuppressive disorders); (4) Active periodontal disease, necrotizing ulcerative gingivitis, periodontal abscess, or oral submucous fibrosis (OSMF); (5) History of periodontal surgery or head/neck radiation within the prior 6 months; (6) Current or former smokers and localized tobacco chewers (tobacco quid habit).

Standardization and Measurement Protocol

All clinical evaluations and radiographic preparations were performed in a standardized single-visit protocol following initial supra-gingival prophylaxis. The maxillary central and lateral incisors were selected as the primary index sites:

Template Preparation & Reference Point Fixation: A transparent Mylar matrix strip was customized by punching a uniform 3-mm circular window. The strip was positioned and temporarily stabilized over the keratinized mucosa such that the window was precisely located 3.0 mm apical to the marginal gingiva mid-buccally.

Radiopaque Marker Application: A specialized radiopaque adhesive cement material (4-META/MMA-TBB based) was placed within the 3-mm punched window to establish a shared, highly reproducible reference fiducial marker for both radiographic slicing and direct physical probing.

CBCT Radiographic Assessment: Three-dimensional CBCT volumetric scans were acquired using the CS 9600 3D Imaging System (Carestream Dental) equipped with a CMOS sensor (1280 × 1024 resolution, FOV ranging from 4×4 to 16×17 cm, voxel size: 75–150 µm, exposure time: 5.5–40 s). On cross-sectional parasagittal reconstructions, the linear soft tissue thickness (STT) was measured from the outer mucosal border (demarcated by the center of the radiopaque marker) to the underlying external cortical bone plate using digital calipers calibrated to 0.01 mm.

Transgingival Probing (Bone Sounding): Following adequate localized topical and infiltration anesthesia, clinical bone sounding was performed perpendicularly through the exact center of the radiopaque cement marker using a standardized UNC-15 periodontal probe (Hu-Friedy, Chicago, IL, USA) fitted with a snug rubber stop. The probe was advanced firmly until distinct osseous resistance was encountered. Upon removal, the linear distance between the probe tip and the rubber stop was measured using a digital vernier caliper sensitive to 0.1 mm. Following recording, the adhesive marker was gently de-bonded.

> **Key Methodological Strength:** Establishing the exact same physical coordinates (the geometric center of the 3-mm radiopaque adhesive marker placed 3 mm apical to the gingival margin) eliminated spatial localization bias between the 3D radiographic slices and direct physical sounding.

Statistical Analysis

Data were compiled into Microsoft Excel and analyzed using IBM SPSS Statistics software. Continuous variables are expressed as Mean ± Standard Deviation (SD). Categorical demographic distributions were analyzed using frequency counts and percentages. The Kolmogorov-Smirnov test confirmed the normality of measurement distributions. The independent Student's t-test was conducted to assess differences between TGP and CBCT measurements. A two-tailed p-value < 0.05 was defined as the threshold for statistical significance.

RESULTS

Demographic Profile

A total of 60 subjects completed the study. The demographic profile is detailed in Table 1. The cohort comprised 42 males (70.0%) and 18 females (30.0%). The mean age was 34.30 ± 8.90 years for male participants and 34.70 ±

9.40 years for female participants (overall cohort mean age: 34.42 ± 9.05 years). The age distribution demonstrated high homogeneity between sexes without statistically significant baseline discrepancy.

Table 1: Demographic Profile and Baseline Age Distribution of the Study Cohort (N = 60)

Parameter	Male (n = 42)	Female (n = 18)	Total Cohort (N = 60)
Gender Distribution, n (%)	42 (70.0%)	18 (30.0%)	60 (100.0%)
Age (Years), Mean ± SD	34.30 ± 8.90	34.70 ± 9.40	34.42 ± 9.05
Age Range (Min – Max)	18 — 49 years	19 — 50 years	18 — 50 years

Descriptive statistics applied. SD = Standard Deviation.

Quantitative Comparison of Soft Tissue Thickness

Soft tissue thickness measurements obtained across all 60 index sites by both modalities are summarized in Table 2 and detailed in Table 3.

Transgingival Probing (TGP): The mean soft tissue thickness recorded was **1.95 ± 0.27 mm**, with individual values ranging from a minimum of 1.50 mm to a maximum of 2.40 mm.

Cone-Beam Computed Tomography (CBCT): The mean soft tissue thickness recorded on calibrated digital cross-sections was **1.93 ± 0.31 mm**, ranging from 1.40 mm to 2.60 mm.

Table 2: Comparative Evaluation of Soft Tissue Thickness Measurements Between TGP and CBCT (N = 60)

Diagnostic Modality	Sample Size (n)	Mean STT (mm) ± SD	Range (Min – Max)	Mean Difference	t-value	p-value
Transgingival Probing (TGP)	60	1.95 ± 0.27	1.50 – 2.40 mm			
CBCT Software Measurement	60	1.93 ± 0.31	1.40 – 2.60 mm	**0.02 mm**	0.377	**0.707 ($p \geq 0.05$)***

*Independent Student's t-test. Level of significance: $p \leq 0.05$. Statistically non-significant ($p \geq 0.05$). STT = Soft Tissue Thickness.

Application of the independent Student's t-test demonstrated a test statistic of $t = 0.377$ with a corresponding p-value of 0.707 ($p > 0.05$). The absolute difference between the mean measurements of the two techniques was only 0.02 mm (20 µm), indicating exceptional concordance and verifying that CBCT software measurements do not deviate significantly from physical bone sounding.

Table 3: Complete Individual Site Dataset of Soft Tissue Thickness Measurements (N = 60)

Site ID	TGP (mm)	CBCT (mm)	Diff	Site ID	TGP (mm)	CBCT (mm)	Diff	Site ID	TGP (mm)	CBCT (mm)	Diff
1	1.9	1.7	+0.2	**21**	2.2	2.2	0.0	**41**	1.9	1.9	0.0
2	2.2	2.3	-0.1	**22**	1.5	1.5	0.0	**42**	2.1	2.2	-0.1
3	1.6	1.5	+0.1	**23**	1.9	1.8	+0.1	**43**	1.6	1.6	0.0
4	2.0	2.0	0.0	**24**	2.4	2.5	-0.1	**44**	2.1	2.0	+0.1
5	2.4	2.6	-0.2	**25**	1.6	1.6	0.0	**45**	1.8	1.9	-0.1
6	1.5	1.4	+0.1	**26**	2.1	2.0	+0.1	**46**	2.2	2.3	-0.1

7	1.8	1.8	0.0	**27**	1.8	1.9	-0.1	**47**	1.7	1.8	-0.1
8	2.1	2.0	+0.1	**28**	2.3	2.2	+0.1	**48**	2.0	2.0	0.0
9	1.7	1.6	+0.1	**29**	2.0	2.0	0.0	**49**	2.4	2.3	+0.1
10	2.3	2.0	+0.3	**30**	1.7	1.6	+0.1	**50**	1.6	1.5	+0.1
11	2.0	1.9	+0.1	**31**	2.2	2.5	-0.3	**51**	1.9	1.9	0.0
12	1.6	1.9	-0.3	**32**	1.9	1.8	+0.1	**52**	2.2	2.0	+0.2
13	1.9	1.9	0.0	**33**	1.5	1.4	+0.1	**53**	1.8	1.7	+0.1
14	2.3	2.5	-0.2	**34**	2.4	2.2	+0.2	**54**	2.1	2.0	+0.1
15	1.6	1.5	+0.1	**35**	1.8	1.7	+0.1	**55**	1.7	1.9	-0.2
16	2.2	2.0	+0.2	**36**	2.1	2.2	-0.1	**56**	2.3	2.5	-0.2
17	1.8	1.7	+0.1	**37**	1.6	1.5	+0.1	**57**	2.0	1.9	+0.1
18	2.3	2.6	-0.3	**38**	2.0	1.9	+0.1	**58**	1.5	1.4	+0.1
19	1.7	1.7	0.0	**39**	2.3	2.3	0.0	**59**	2.4	2.3	+0.1
20	2.0	1.9	+0.1	**40**	1.7	1.6	+0.1	**60**	1.9	1.8	+0.1

Diff = (TGP − CBCT) in millimeters. Mean TGP: 1.95 ± 0.27 mm; Mean CBCT: 1.93 ± 0.31 mm.

DISCUSSION

Clinical Relevance of Soft Tissue Thickness

The quantitative appraisal of vertical soft tissue thickness (STT) has shifted from an academic consideration to a fundamental clinical necessity in contemporary reconstructive dentistry [10, 11]. In implantology, a baseline mucosal thickness ≥ 2.0 mm is essential to establish an effective biological seal around transmucosal abutments without inducing crestal bone remodeling [28]. When soft tissue volume is thin (< 2.0 mm), bone remodeling inevitably occurs to compensate for the biological width dimension [19, 28]. Similarly, in mucogingival plastic surgery, baseline flap thickness > 1.1 mm is a critical prognostic factor for achieving complete root coverage [18].

Methodological Innovation of the Radiopaque Marker Protocol

The core challenge in non-invasive soft-tissue imaging via CBCT has historically been low soft-tissue contrast resolution and mucosal compression by adjacent lip and cheek tissues [4, 6]. Previous researchers utilized soft-tissue retractors (ST-CBCT) or radio-dense paste [4, 22]. In the present study, the combination of a Mylar matrix strip with a 3-mm punched window and a radiopaque 4-META/MMA-TBB adhesive cement marker established an exact, shared mathematical reference fiducial point. This protocol eliminated operator angulation bias and allowed direct millimeter-to-millimeter correspondence between physical bone sounding and 3D digital cross-sections.

Comparison with the Literature

The findings of this study demonstrate strong agreement with existing periodontal diagnostic literature. Gotam Das et al. (2022) reported a high correlation (r = 0.814, p < 0.001) between TGP (1.12 ± 0.24 mm) and CBCT (1.19 ± 0.21 mm) in anterior maxillary teeth [25]. Similarly, Navina Ravindran et al. (2024) observed no statistically significant difference between TGP (1.61 ± 0.20 mm) and ST-CBCT (1.66 ± 0.23 mm, p = 0.61) [26]. Warad et al. (2018) and Mohamed El Khalifa et al. (2021) confirmed that CBCT software calculations provide an intraclass correlation coefficient (ICC) exceeding 0.92 when cross-referenced with clinical sounding [8, 23].

Conversely, studies evaluating ultrasonic devices (e.g., Kloukos et al., 2018; Gürlek et al., 2018) highlighted notable procedural variability due to manual pressure compression and transducer angulation challenges [16, 24]. Direct comparison studies with histology by Hamoun Sabri et al. (2025) demonstrated that quantitative methods (both CBCT and TGP) accurately reflect histological thickness (r = 0.89–0.98), whereas qualitative visual probing results in frequent phenotype misclassification near the 1.0 mm critical threshold [2].

Interdisciplinary, Service Marketing, and Technology Adoption Implications

Beyond clinical periodontics, the results of this study carry profound implications for healthcare management, service marketing, and digital technology adoption:

Patient-Centric Value Creation: In competitive healthcare markets, substituting invasive, uncomfortable procedures (anesthetic needles and bone sounding) with non-invasive digital alternatives significantly reduces patient anxiety, enhances procedural comfort, and elevates perceived service quality (SERVQUAL dimensions of empathy, assurance, and responsiveness).

Workflow Digitization and Marketing Advantage: Incorporating standardized non-invasive 3D phenotypic mapping into pre-surgical diagnostic consultations provides clinics with a strong technological differentiator, reinforcing trust and patient compliance.

Interdisciplinary Risk Management: Objective millimetric soft-tissue data enables precise risk stratification across implant, orthodontic, and prosthodontic service lines, avoiding costly post-operative esthetic complications and biological failures.

Limitations and Regional Context

This investigation provides the first systematic clinico-radiographic dataset validating CBCT soft-tissue thickness in the North Gujarat population. Limitations include the sample size of 60 subjects recruited from a single regional academic institution and the anatomical focus restricted to the maxillary anterior segment. Future multicentric studies evaluating posterior zones, mandibular arches, and lower-dose radiographic protocols are recommended.

CONCLUSION

marker protocol demonstrates exceptional diagnostic accuracy and reproducibility, yielding measurements with a negligible 0.02 mm deviation from conventional transgingival probing. The protocol provides a non-invasive, operator-independent, and standardized platform for pre-surgical treatment planning, successfully bridging the diagnostic gap between clinical periodontics, digital imaging technology, and patient-centered healthcare delivery....

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