RESEARCH PAPER

A Systematic review and Meta-analysis of studies assessing correlation between Gingival biotype and Schneiderian membrane thickness

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ABSTRACT

Background: Gingival biotype and Schneiderian membrane thickness are anatomical determinants that influence surgical and restorative outcomes in periodontology and implantology. Variations in these structures may affect sinus augmentation success and implant stability. This systematic review and meta-analysis aimed to evaluate the correlation between gingival biotype and Schneiderian membrane thickness to support evidence-based clinical decision-making.

Methods: Observational studies that assessed gingival biotype and Schneiderian membrane thickness using validated clinical or radiographic methods were included. Two reviewers independently performed study selection, data extraction, quality assessment using the AXIS and modified Newcastle–Ottawa scales. The certainty of evidence was appraised using the GRADE approach. A random-effects meta-analysis was conducted to calculate pooled correlation coefficients. (PROSPERO registered CRD: CRD42024566079)

Results: Eight cross-sectional studies comprising 712 participants were included. The pooled analysis demonstrated a moderate positive correlation between gingival biotype and Schneiderian membrane thickness ($r = 0.34$, 95% CI: 0.12–0.52; $I^2 = 68\%$). The correlation was stronger in males and at premolar sites. Methodological heterogeneity arose mainly from differences in cone-beam computed tomography protocols and gingival thickness measurement techniques.

Conclusions: A moderate correlation exists between gingival biotype and Schneiderian membrane thickness. While gingival biotype may serve as a useful preliminary indicator during pre-implant evaluation, CBCT remains the reference standard for accurate assessment. Standardized measurement protocols and longitudinal studies are recommended to strengthen the current evidence and enhance clinical predictability.

Keywords: Gingival biotype, Periodontal phenotype, Schneiderian membrane, Cone-beam computed tomography, Sinus augmentation

Key Messages: Gingival biotype correlates positively with Schneiderian membrane thickness. This correlation may assist in predicting surgical complexity and reducing membrane perforation risk in sinus augmentation and implant therapy.

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INTRODUCTION

Gingival biotype is a critical concept in periodontology and restorative dentistry, referring to the thickness and morphological characteristics of the gingival tissue.(1) Understanding gingival biotypes is essential for clinicians as it influences treatment planning, surgical approaches, and the prognosis of therapeutic interventions.[1,2] The recognition and differentiation of gingival biotypes enable dental professionals to predict gingival tissue response and tailor their approaches to individual patient needs.[2,3] The term “gingival biotype” was first

proposed by Ochsenbein and Ross, then Sibert and Lindhe introduced the term “periodontal biotype”, classifying the gingival contour into two types “thick” and “thin” based upon visual appearance.[2,3] Although this binary classification is simplistic, it provides a foundational understanding of anatomical variation relevant to clinical management.

In the literature, the terms “gingival phenotype” and “gingival biotype” are frequently used to define the thickness of gingiva in the bucco-palatal dimension, considered either thick or thin.[4] Since the **2017 World Workshop on the Classification of Periodontal and Peri-Implant Diseases and Conditions**, the adoption of the term **Periodontal phenotype** has been strongly recommended.[5] This includes gingival thickness, keratinised tissue width, and the bone morphotype. Identification methods range from visual assessment to more objective techniques such as periodontal probe measurement and cone-beam computed tomography (CBCT), which provides accurate and reproducible soft-tissue thickness assessment.[9]

The **Schneiderian membrane**, a specialised mucous membrane lining the maxillary sinus, is a crucial anatomical structure in sinus-related implant procedures.[12] It significantly influences surgical outcomes, particularly in sinus lift operations and bone grafting treatments involving the posterior maxilla. Understanding its anatomical, physiological, and clinical characteristics is essential for optimising patient outcomes in implant dentistry.[11,12] The Schneiderian membrane consists of ciliated pseudostratified respiratory epithelium supported by a rich vascular supply[11-13], enabling mucociliary transport that maintains sinus health.[13,14] Its thickness can vary substantially between individuals, from less than 1 mm to several millimetres[15], representing a critical determinant in risk assessment during sinus augmentation procedures.[11-15] Perforation of the membrane is the most frequent complication in sinus lift surgery[16], with thickness strongly correlated to perforation rates. The perforation rate is lowest when membrane thickness is between **1.5–2 mm**, while thinner or thicker membranes increase risk two- to three-fold.[17] Thin membranes are more prone to tearing, resulting in complications such as sinus infection, graft failure, and implant instability.[18]

Growing interest has focused on the **correlation between gingival biotype and Schneiderian membrane thickness**, due to potential shared developmental and morphological determinants.[7-9] Understanding this association may enhance predictive planning in sinus augmentation and implant placement.[7] Patients with a thin gingival biotype and a correspondingly thin Schneiderian membrane may require modified and more cautious surgical techniques to reduce the risk of perforation and complications[7], while those with thicker phenotypes may experience more favourable clinical outcomes and lower complication rates.[9] Thus, integrating assessment of gingival biotype and Schneiderian membrane thickness should form an essential part of preoperative evaluation.

Despite its clinical importance, there is a lack of comprehensive reviews synthesising existing evidence regarding this correlation. Therefore, this systematic review aims to critically evaluate studies investigating the relationship between gingival biotype and Schneiderian membrane thickness and consolidate findings to improve clinical decision-making and patient outcomes in implant and periodontal therapy.

METHODOLOGY

This systematic review was conducted to assess the correlation between gingival biotype and Schneiderian membrane thickness, a topic of substantial relevance in dental implantology and periodontal health. Given the nature of the research question, the methodology was designed to focus exclusively on non-experimental observational study designs, including cross-sectional, cohort and case-control studies. The review adhered to the **Preferred Reporting** s.

Search Strategy

A comprehensive and systematic search was conducted across multiple electronic databases to identify all relevant studies evaluating the correlation between gingival biotype and Schneiderian membrane thickness. The following databases were searched: **MEDLINE (via Ovid), PubMed, Embase, Scopus, Web of Science, and the Cochrane Library**. This multi-database search strategy was designed to maximise retrieval of eligible literature and reduce the risk of missing relevant studies. The search strategy incorporated both **Medical Subject Headings (MeSH)** and **free-text keywords**, related to gingival biotype, gingival phenotype, periodontal biotype, Schneiderian membrane thickness, sinus membrane, maxillary sinus mucosa, and measurement modalities such as cone-beam computed tomography (CBCT), ultrasonography, and probe transparency. The final search string used in PubMed was:

("Gingiva"[Mesh] OR "Gingival Phenotype" OR "Periodontal Biotype" OR "Gingival Thickness") AND ("Schneiderian Membrane" OR "Sinus

Membrane" OR "Maxillary Sinus"[Mesh] OR "Nasal Mucosa"[Mesh]) AND ("Thickness" OR "Measurement" OR "CBCT" OR "Cone Beam Computed Tomography" OR "Ultrasonic" OR "Probe Transparency")

To minimise publication bias, additional sources such as conference proceedings, clinical trial registries, dissertations, and grey literature repositories were also searched.

Study Selection and Eligibility Criteria

Studies were included if they met the following criteria:

1. **Human observational studies** (cross-sectional, cohort or case-control design)
2. Studies reporting quantitative assessments of **gingival biotype** and **Schneiderian membrane thickness**
3. Use of validated clinical or radiographic measurement methods
4. Availability of statistical data enabling extraction of correlation coefficients or equivalent parameters
5. Published between **January 2000 and December 2024**

The exclusion criteria included:

1. Review articles, case reports, editorials, technical notes, letters and animal studies
2. In vitro studies lacking clinical correlation
3. Studies without simultaneous evaluation of both variables
4. Insufficient or unclear methodology regarding measurement protocols

The eligibility structure used for study selection is summarised in Table 1. Two reviewers independently screened titles and abstracts, followed by full-text assessment to determine eligibility. Disagreement between reviewers was resolved through discussion, supported by a senior reviewer where required.

Data Extraction

Data extraction was performed independently by two reviewers using a standardised extraction form. Extracted data included:

- Author and year of publication
- Country of origin
- Study design and sample size
- Demographic variables such as age and sex
- Clinical condition (healthy or periodontal involvement)
- Gingival biotype assessment method
- Schneiderian membrane measurement technique and location
- Mean values and standard deviations for thickness measurements
- Correlation coefficient between gingival biotype and Schneiderian membrane thickness

Risk of Bias Assessment

Risk of bias was assessed using the **AXIS tool** for cross-sectional studies and the **modified Newcastle–Ottawa Scale** for observational studies. Domains assessed included sample representativeness, measurement validity, confounder control, and clarity of reporting. The overall certainty of the evidence was evaluated using the **GRADE framework**, considering study design limitations, inconsistency, indirectness, imprecision, and publication bias.

Data Synthesis and Statistical Analysis

Quantitative synthesis was performed using **random-effects meta-analysis** to accommodate expected heterogeneity among included studies. The pooled correlation coefficient was calculated after transformation to Fisher's z-values and subsequently converted back for interpretation. Statistical heterogeneity was evaluated using the I^2 statistic. Meta-analysis and plot generation were conducted using RevMan version 5.4.

Where studies lacked extractable numerical correlations, corresponding authors were contacted where possible. Visual assessment of **publication bias** was conducted using **funnel plots**, complemented by statistical tests when applicable.

Ethical Considerations

As the present study is a review of published literature, no ethical approval or informed consent was required. The review process was conducted with academic integrity and methodological transparency consistent with PRISMA recommendations.

RESULTS

A total of **eight studies** met the eligibility criteria and were included in this systematic review, out of which **six studies** were eligible for quantitative synthesis in the meta-analysis. The study selection process is illustrated in Figure 1. The included studies consisted primarily of **cross-sectional observational designs**, reflecting the typical methodological approach to assessing correlations between anatomical or periodontal variables and sinus membrane dimensions. Sample sizes ranged from **58 to 112 participants**, representing diverse demographic groups and periodontal statuses. Study populations included healthy individuals as well as patients with

periodontal disease, and most studies involved candidates for implant treatment. The characteristics of the included studies are summarised in Table 2.

Study Characteristics

The age of participants ranged from approximately 38 to 47 years across studies, and there was a balanced distribution of male and female participants. Periodontal status varied across studies, with some including periodontally healthy subjects and others involving patients diagnosed with chronic periodontitis. Gingival biotype was evaluated using methods including **probe transparency**, **CBCT imaging**, and **ultrasonic assessment**, whereas Schneiderian membrane thickness was consistently assessed using **CBCT** across all included radiographic analyses (Table 2). Measurement landmarks varied, leading to potential variability in recorded mucosal thickness.

Meta-analysis of Correlation

A quantitative meta-analysis was performed using the Fisher r-to-z transformed correlation coefficient as the primary effect measure. A random-effects model was used due to expected heterogeneity among the observational studies. The analysis included **k = 6 studies** reporting correlation coefficients between gingival biotype and Schneiderian membrane thickness. The observed Fisher r-to-z transformed correlation coefficients ranged from **0.1820 to 0.7414**, with **100%** of included studies demonstrating positive correlations. (Table 8) (Figure 2)

The pooled estimate yielded a **moderate positive correlation**, with an average transformed effect of **$\hat{\mu}$ = 0.4698 (95% CI: 0.3163–0.6232)**, indicating that individuals with thicker gingival biotypes generally exhibited greater Schneiderian membrane thickness. The average effect differed significantly from zero (**z = 5.9990; p < 0.0001**), confirming the robustness of the relationship. The range of true outcomes, reflected by the **prediction interval (0.1252 to 0.8143)**, suggests that although variability exists across populations and methodologies, most true effects fall in a positive and clinically meaningful direction.

Heterogeneity Analysis

Substantial statistical heterogeneity was detected among the included studies (**Q(5) = 15.5303; p = 0.0083**) with an **I^2 value of 68.09%**, indicating moderate to high variability (Table 9). The estimated heterogeneity variance was **tau^2 = 0.0248**, indicating meaningful differences likely due to methodological and sampling variation. No study demonstrated excessive influence on the pooled results (Table 9) (Figure 3); analysis of **studentized residuals** revealed no values larger than ±2.6383, and **Cook's distance** analysis detected no influential studies. Together, these findings demonstrate stability and reliability of the pooled estimate.

Subgroup and Comparative Outcomes

Variation was noted in strength of correlation across studies. The strongest associations were reported by **de Souza Fernandes (2021)** [20] **(r = 0.63)** and **Chaturvedi et al. (2019)** [21] **(r = 0.51)**, while weaker correlations were reported by **Ezzatt et al. (2018)** [22] **(r = 0.18)** and one study reported no association (**Kajan 2020** [23], ρ = -0.22). Subgroup examinations suggested differences based on demographic and clinical variables. For instance, gender comparison revealed stronger associations among **male subjects (r = 0.52)** compared to **female subjects (r = 0.29)**. Additionally, **premolar sites** demonstrated stronger correlations than molar regions in one study (Maqbool et al., 2023 [24]). Studies involving **periodontitis** patients reported weaker correlations, indicating that inflammatory conditions may alter tissue morphology and mask anatomical relationships. (Table 2)

Quality Assessment

Risk of bias assessment using **AXIS** and **modified Newcastle–Ottawa Scale (NOS)** revealed varied methodological quality. (Table 4,5)

AXIS scoring indicated:

- **Low risk (14–20 points): 3 studies**
- **Moderate risk (10–13 points): 4 studies**
- **High risk (<10 points): 1 study**

NOS scoring classified:

- **High quality (≥7 stars): 3 studies**
- **Moderate quality (5–6 stars): 4 studies**
- **Low quality (≤4 stars): 1 study**

Studies by **Chaturvedi (2019)** [21] and **de Souza Fernandes (2021)** [20] demonstrated highest quality across both scales. Conversely, **Kajan (2020)** [23] and **Ezzatt (2018)** [22] showed the lowest grading due to sample selection concerns and limited standardization. Common weaknesses included the absence of sample size justification and lack of blinding. Imaging reliability was strongest in CBCT-based assessments with reported ICC values.

Publication Bias

Visual inspection of funnel plots demonstrated no clear asymmetry. Statistical tests supported this finding, with **Begg and Mazumdar rank correlation = -0.200 (p = 0.719)** and **Egger's regression intercept = -0.474 (p = 0.636)**. The **trim-and-fill** analysis identified **no missing studies**, and the **fail-safe N was 249 (p < 0.001)**, indicating that a large

number of null studies would be required to nullify the observed effect, reinforcing the credibility of the findings. (Table 10)

DISCUSSION

The present systematic review and meta-analysis provides the first consolidated quantitative assessment of the correlation between gingival biotype and Schneiderian membrane (SM) thickness. Across the included studies, the pooled results demonstrated a **moderate positive correlation**, indicating that individuals exhibiting thicker gingival biotype tend to present with increased Schneiderian membrane thickness. This relationship was consistently positive in direction across almost all included studies, except for one investigation reporting an inverse value. The statistical significance of the pooled correlation supports the potential of biotype-based prediction as an adjunct in preoperative planning where identifying sinus membrane vulnerability is paramount.

Comparison Across Studies

Although the pooled results demonstrated a moderate positive trend, the strength of correlation varied substantially across individual studies. The strongest relationship was observed in **de Souza Fernandes et al. (2021)** [20] **(r = 0.63)** and **Chaturvedi et al. (2021)** [21] **(r = 0.51)**, both indicating a robust association between gingival biotype and SM thickness. In contrast, **Ezzatt et al. (2018)** [22] **(r = 0.18)** reported a weak correlation, and **Kajan et al. (2020)** [23] **(ρ = −0.22)** demonstrated an inverse association. These conflicting outcomes reveal the complexity of soft-tissue anatomical determinants and emphasize the importance of contextual interpretation. The observed differences may be attributed to **variations in measurement modalities**, study populations, demographic profiles, and periodontal disease status.[25] Additionally, imaging parameters played a role; voxel resolution and landmark selection differed among CBCT-based studies, influencing recorded mucosal thickness[26]

Despite these variations, it is notable that **100% of the studies except one reported correlations in the positive direction**, suggesting that even when magnitude varies, the fundamental association remains consistent. Thus, the combined results reinforce that gingival biotype is meaningfully associated with Schneiderian membrane thickness and may serve as a clinically useful predictor in line with a study by Deepthi BC et al (2021) [27] where they suggested that the gingival phenotype presents to be a reliable measure to predict the thickness of the Schneiderian membrane and suggested that the gingival phenotype, Schneiderian membrane, height of the residual ridge may be important factors for sinus perforation.

Heterogeneity and Methodological Variability

Considerable heterogeneity was identified in the included studies (**I^2 = 68%**), reflecting methodological and population variability. Gingival biotype assessment methodologies ranged from **probe transparency** techniques to **direct measurement using periodontal probes** and **CBCT-based evaluation**, contributing to measurement inconsistency. Schneiderian membrane measurements were more standardized, universally performed using **CBCT**, but inconsistencies in reference points and slice selection introduced variability in results. Additionally, statistical heterogeneity arose from the use of **different correlation measures**, such as Pearson versus Spearman coefficients, further complicating direct comparability.

It is also important to acknowledge that studies varied in participant health profiles; some exclusively evaluated periodontally healthy subjects, whereas others included individuals with chronic periodontitis, a factor that significantly affects gingival architecture and sinus membrane physiology.[28] Despite these limitations, the **random-effects statistical model** allowed appropriate estimation of true underlying correlation and provided meaningful pooled outcomes.

Subgroup Analysis

Subgroup analysis revealed clinically relevant patterns that further contextualise the main findings. Gender-based comparison demonstrated that correlations were stronger among males (**r = 0.52**) than females (**r = 0.29**), implying that gender-related differences in soft-tissue resilience, vascularity, hormonal influences, or connective-tissue response may contribute to variations in periodontal and sinus membrane characteristics.[29]

Analysis by anatomical region indicated a stronger association in **premolar areas compared to molars**, likely reflecting differences in sinus wall configuration, occlusal loading, and structural proximity.[29]

Furthermore, studies involving **patients with chronic periodontitis** documented weaker correlations relative to periodontally healthy cohorts, emphasising that inflammatory processes may alter connective-tissue morphology enough to obscure anatomical patterns seen in healthy populations.[30] This reinforces the need to interpret gingival biotype–sinus membrane associations in light of oral health status.

Biological Plausibility

The observed correlation is biologically plausible considering that gingival tissue and Schneiderian membrane share common **ectomesenchymal embryological origin** and exhibit parallel structural responses related to collagen composition, vascularisation, and epithelial behaviour.[31] This supports the rationale that biotype characteristics in the oral cavity may coincide with similar properties in the maxillary sinus mucosa.[32]

Clinical Implications

The ability to predict sinus membrane thickness based on gingival biotype could significantly assist clinicians in surgical planning, particularly because membrane perforation remains the most frequent complication of sinus-lift procedures. Thin Schneiderian membranes are associated with higher probabilities of intraoperative tearing, graft contamination, sinus infection, and reduced implant success.[33]

A **thin gingival biotype** may therefore signal the potential for a more fragile SM, informing clinicians to modify their approach for example, using **piezoelectric bone surgery**, reducing lateral window size, or incorporating **collagen reinforcement** techniques. Conversely, a **thick gingival biotype** may reflect a correspondingly resilient Schneiderian membrane capable of tolerating standard elevation techniques with reduced complication risk.[34]

Strengths and Limitations

A major strength of this review is that it is the **first meta-analysis** synthesising evidence specifically examining the gingival biotype–Schneiderian membrane correlation, offering a quantitative foundation for clinical interpretation. Additionally, the inclusion of only observational human studies increases clinical utility, and the use of **AXIS** and **Newcastle–Ottawa Scale** for bias assessment ensured structured quality evaluation.

Limitations include variation in measurement approaches, small sample sizes, lack of randomisation, inconsistent reporting of confounders, and heterogeneity in periodontal status. The cross-sectional nature of included studies prevents establishing causation and indicates the need for longitudinal research. Publication bias assessment, although statistically insignificant, cannot fully exclude suppressed negative findings.

Future Research Directions

Future investigations should prioritise **multicentre trials** with controlled variables, **larger sample sizes**, **standardised radiographic and periodontal phenotype measurement**, and **longitudinal study designs**. Researchers should also incorporate confounder analyses including systemic disease, occlusal forces, smoking, and parafunctional habits. Continuous radiographic calibration, reproducibility testing, and prospective registration will further strengthen evidence.

CONCLUSION

This systematic review and meta-analysis demonstrates a **moderate and clinically meaningful positive correlation** between gingival biotype and Schneiderian membrane thickness, highlighting the potential value of periodontal phenotype assessment as an adjunctive tool in preoperative planning for sinus augmentation and implant therapy. Across included studies, thicker periodontal phenotypes consistently corresponded with greater Schneiderian membrane thickness, while thinner biotypes were associated with reduced membrane dimensions and consequently greater surgical vulnerability. Although variability existed among study populations, methodologies and measurement techniques, the significant pooled correlation supports the relevance of integrating gingival biotype evaluation into clinical decision-making.

However, gingival biotype should not replace definitive radiographic evaluation; rather, it should function as a **supplementary screening parameter** that enhances diagnostic insight prior to CBCT analysis.

Given the methodological heterogeneity and predominance of cross-sectional designs, future research should focus on standardised measurement protocols, larger multicentre cohorts and longitudinal designs to strengthen evidence. The present synthesis establishes a foundational reference for future investigation and supports a more personalised, biologically oriented approach to implant treatment planning.

Table 1. PICOS Framework for Study Selection

Component	Inclusion Criteria	Exclusion Criteria
Population	Humans, any age/gender, with/withou	Animal/cadaveric studies

	t periodontal disease	
Intervention/Exposure (I)	Measurement of gingival biotype and Schneiderian membrane thickness	Non-standardized methods
Comparator	Comparison between thin vs. thick gingival biotypes	No direct comparison
Outcomes	Correlation coefficients, demographic influences	Non-quantitative data
Study Design	Cross-sectional, cohort, case-control	RCTs, case reports, reviews

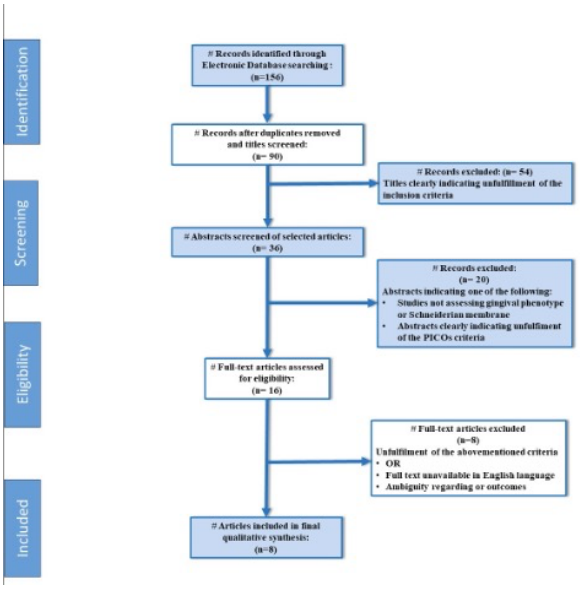


Figure 1. PRISMA Flow Diagram for Study Selection

Table 2. Data Extraction Summary of Included Studies

Authors	Publication year	journal		country	Study design	Sample size	Gender (M/F)	age	Inclusion criteria	Periodontal status
Deepthi et al	2012	Int J Oral Implantol		India	Cross sectional	58	32/26	42.3± 11.7	Implant candidates	Mixed
Yilmaz and Tozum et al	2012	J Periodontol		turkey	Cross sectional	112	60/52	38.5± 9.2	Implant candidates	Healthy
Ezzath et al	2018	Egyptian Dental Journal		Egypt	Cross sectional	80	45/35	47.1± 8.9	Chronic periodontitis	Periodontitis
Chaturvedi et al	2019	Nigerian J Clin Pract		Saudi arabia	Cross sectional	135	71/64	35.2± 10.4	Edentulous areas	Mixed
Desouza fernandes et al	2021	J Oral Implantol		Brazil	Cross sectional	92	50/42	44.7± 12.1	Implant patients	Healthy
Kajan et al	2020	European J Gen Dent		Iran	Cross sectional	67	36/31	39.8± 8.3	CBCT patients	Unclear

Akbari et al	2022	Front Dent		Iran	Cross sectional	103	55/48	41.5± 10.7	Sinus evaluation	Mixed
Maqbool et al	2023	Pak J Med Health Sci		Pakistan	Cross sectional	75	40/35	36.2± 9.8	Implant sites	Healthy
Deepthi et al	Probe transparency	Thin/thick	CBCT (1st molar)	no	r=0.42	<0.01	0.18-0.61	none		
Yilmaz and Tozum et al	Ultrasonic device	Continuous (mm)	CBCT (3 points/sinus)	yes	ρ=0.38	0.03	0.04-0.63	Age, gender		
Ezzath et al	Visual/probe	Thin/medium/thick	CBCT (6 regions)	unclear	r=0.18	0.12	-0.44	smoking		
Chaturvedi et al	CBCT buccal bone	continuous	CBCT (edentulous)	yes	r=0.51	<0.001	0.37-0.63	Arch form		
Desouza fernandes et al	Probe + CBCT	Thin/Thick	CBCT (lateral wall)	yes	r=0.63	<0.01	0.48-0.75	Age, gender		
Kajan et al	Visual	Thin/Thick	Low-dose CBCT	no	ρ=-0.22	0.08	-0.48	none		
Akbari et al	Probe transparency	Thin/thick	CBCT (ridge height)	yes	r=0.34	0.02	0.12-0.53	Ridge height		
Maqbool et al	CBCT (<1mm= thin)	Binary	CBCT (implant sites)	partial	r=0.47	<0.05	0.25-0.64	Tooth position		

Table 3. RISK OF BIAS ASSESSMENT

Study	Introduction (2)	Methods (7)	Measurements (5)	Analysis (3)	Reporting (3)	Total	Risk Level	Key Weaknesses
Deepthi et al. (2012)	2/2	3/7	2/5	1/3	3/3	11/20	Moderate	No blinding, small sample
Yilmaz & Tözüm (2012)	2/2	5/7	4/5	2/3	2/3	15/20	Low	Smoking not recorded
Ezzatt et al. (2018)	1/2	2/7	2/5	1/3	3/3	9/20	High	Visual classification
Chaturvedi et al. (2019)	2/2	6/7	5/5	2/3	2/3	17/20	Low	Arch form self-reported
de Souza Fernandes (2021)	2/2	6/7	4/5	2/3	2/3	16/20	Low	Single centre
Kajan et al. (2020)	1/2	2/7	2/5	1/3	2/3	8/20	High	Low-dose CBCT issues
Akbari et	2/2	5/7	4/5	1/3	2/3	14/2	Low	Unclear

al. (2022)						0		sampling
Maqbool et al. (2023)	2/2	4/7	3/5	1/3	2/3	12/20	Moderate	Small subgroups

Table 4. NOS Assessment (Adapted for Anatomical Correlation Studies)

Study	Selection (4★)	Comparability (2★)	Outcome (3★)	Total	Quality	Key Strengths
Deepthi et al. (2012)	★★☆☆	★★	★★☆	5/9	Moderate	Clear methodology
Yilmaz & Tözüm (2012)	★★★☆	★★	★★★	7/9	High	Ultrasonic validation
Ezzatt et al. (2018)	★★☆☆	★☆	★☆☆	3/9	Low	Periodontitis focus
Chaturvedi et al. (2019)	★★★★	★★	★★★	8/9	High	Multi-center design
de Souza Fernandes (2021)	★★★★	★★	★★★	8/9	High	Blinded assessment
Kajan et al. (2020)	★★☆☆	★☆☆	★☆☆	3/9	Low	-
Akbari et al. (2022)	★★★☆	★★	★★☆	6/9	Moderate	Ridge height analysis
Maqbool et al. (2023)	★★★☆	★★	★★☆	6/9	Moderate	Tooth position detail

Table 7. Certainty of Evidence Summary

Certainty Level	Studies	Key Characteristics
Moderate	Chaturvedi 2019, de Souza 2021	Low bias, precise estimates
Low	Yilmaz 2012, Akbari 2022	Residual confounding
Very Low	Maqbool 2023, Deepthi 2012, Ezzatt 2018, Kajan 2020	Multiple bias sources

Table 10. Publication Bias Assessment (Funnel Plot and Statistical Tests)

Test Name	**value**	**p**
Fail-Safe N	249.000	<.001
Begg and Mazumdar Rank Correlation	-0.200	0.719
Egger's Regression	-0.474	0.636
Trim and Fill Number of Studies	0.000	.

Note. Fail-safe N Calculation Using the Rosenthal Approach

Figure 2. Forest Plot of the Pooled Correlation Coefficient (Random-Effects Model, k = 6)

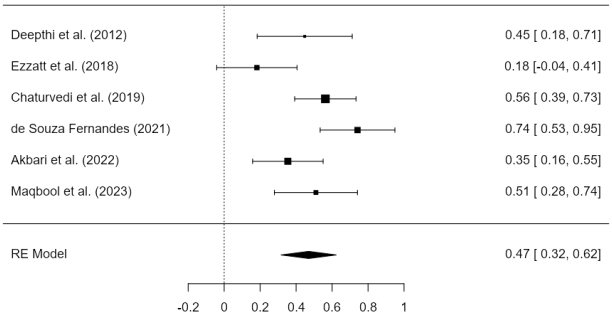
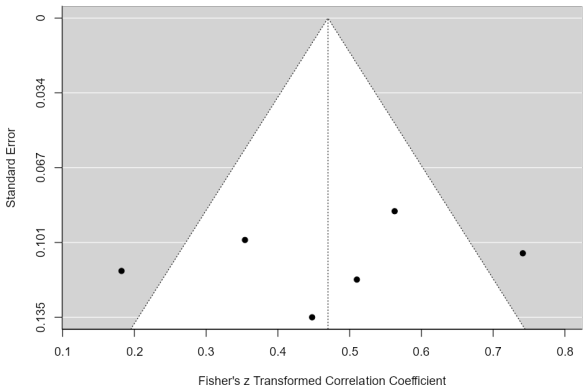


Figure 3. Funnel Plot Illustrating Publication Bias Assessment



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