

Implant Imaging for Cortical Anchorage: A PRISMA-Guided Critical Review of OPG and CBCT Literature

Dr. Kaushik Dutta^{1*}, Dr. Madhumita Mazumdar², Dr. Tamal Kanti Pal³, Dr. Jyotirmoy Chatterjee⁴, Dr. Debopriyo Chatterjee⁵

¹PhD Scholar, Department of Oral and Dental Science, JIS University, Kolkata; Professor and Head of the Department, Department of Oral Medicine and Radiology, Guru Nanak Institute of Dental Sciences and Research, Kolkata. (Corresponding Author)

²Professor and Head of the Department, Department of Oral and Dental Science, JIS University, Kolkata.

³Professor Emeritus, Department of Oral and Dental Science, JIS University, Kolkata.

⁴Professor and the Dean of Research, JIS Institute of Advanced Studies and Research, Kolkata.

⁵MDS-PGT, Department of Oral Medicine and Radiology, Guru Nanak Institute of Dental Sciences and Research, Kolkata.

*Corresponding author: Dr. Kaushik Dutta, PhD Scholar, Department of Oral and Dental Science, JIS University, Kolkata; Professor and Head, Department of Oral Medicine and Radiology, Guru Nanak Institute of Dental Sciences and Research, Kolkata

Email: kaushik.dutta@jisuniversity.ac.in

Received: 29th May, 2026; Revised: 10th June, 2026; Accepted: 14th June, 2026; Available Online: 16th June, 2026

ABSTRACT

Background

Cortical anchorage concepts have increasingly influenced implant dentistry, particularly in anatomically compromised situations where conventional endosseous implant approaches are constrained. Despite this shift, radiographic imaging strategies supporting implant planning remain largely grounded in paradigms developed for trabecular bone-dependent implant placement.

Objective

This PRISMA 2020-guided critical review aimed to synthesize indexed literature related to orthopantomogram (OPG) and cone beam computed tomography (CBCT) in implant imaging, with particular emphasis on unresolved conceptual, methodological, clinical, and ethical gaps relevant to cortical anchorage.

Materials and Methods

Electronic database searches were conducted in PubMed/MEDLINE, Scopus, and the Cochrane Library for studies published between January 2000 and March 2026. Following systematic screening of 812 records and removal of duplicates, 586 records underwent title and abstract screening. Full-text assessment was performed for 130 studies, of which 48 indexed studies met predefined eligibility criteria and were included in qualitative synthesis.

Results

The review identified persistent absence of validated radiological definitions of cortical suitability, continued empirical reliance on panoramic imaging without established thresholds, lack of standardized CBCT protocols tailored to cortical engagement, weak and inconsistent correlations between imaging findings and clinical outcomes, limited formal integration of oral and maxillofacial radiology expertise into implant decision-making, and underdeveloped ethical frameworks addressing interpretive uncertainty and imaging justification.

Conclusions

Current OPG and CBCT protocols lack the standardization necessary to safely guide cortical anchorage. Overcoming this relies on shifting from purely descriptive radiological reporting to outcome-validated, trajectory-based frameworks that bridge the gap between initial radiographic interpretation and active surgical execution.

Keywords: Cortical Implants; Cone Beam Computed Tomography; Panoramic Radiography; Implant Imaging; Oral Radiology; Ethics.

How to cite this article: Dutta K, Mazumdar M, Pal TK, Chatterjee J, Chatterjee D. Implant Imaging for Cortical Anchorage: A PRISMA-Guided Critical Review of OPG and CBCT Literature. *Int J Drug Deliv Technol.* 2026;16(60s):683-696. DOI: 10.25258/ijddt.16.60s.79

Source of support: Nil.

Conflict of interest: None

1. Introduction

Cortical anchorage in implant dentistry has evolved primarily from clinical necessity rather than theoretical preference. Severe alveolar ridge

resorption, sinus pneumatization, limited vertical bone availability, compromised trabecular density, and anatomical restrictions often reduce the feasibility of conventional endosseous implant placement [1–5]. In such circumstances, implant

stability increasingly depends upon engagement of dense cortical and basal bone structures rather than reliance on cancellous bone volume alone.

This shift fundamentally alters the radiological requirements of implant planning. Conventional implant imaging protocols were historically designed around crestal implant placement concepts emphasizing ridge height, ridge width, trabecular bone availability, delayed loading, and osseointegration-dependent healing [1,2]. Cortical anchorage strategies, however, frequently involve oblique trajectories, bicortical stabilization, engagement of remote cortical structures, immediate or early loading, and mechanical stabilization beyond conventional crestal pathways [5,37,38].

Radiographic imaging is expected to reduce uncertainty and facilitate safe surgical planning. Panoramic radiography and cone beam computed tomography (CBCT) currently constitute the principal imaging modalities used in implant dentistry [11–16]. Panoramic radiography continues to be widely employed because of accessibility, lower radiation exposure, and cost-effectiveness. However, limitations related to magnification, distortion, lack of buccolingual visualization, and superimposition are well documented [11–13].

CBCT fundamentally improved implant planning by providing accurate, three-dimensional assessments of alveolar bone and adjacent vital structures [14–18]. However, linear accuracy alone does not satisfy the requirements of cortical anchorage. The operating clinician must determine if the target cortical bone is continuous, structurally sound, and accessible along the intended trajectory of mechanical engagement.

Despite this shift toward cortical reliance, most CBCT protocols still reflect traditional crestal-loading paradigms rather than targeted cortical engagement strategies. Clinical reports frequently rely on subjective descriptors—such as “adequate cortical bone” or “dense cortical support”—yet fail to provide validated, reproducible radiological thresholds [8–10]. Consequently, the literature exhibits a significant disconnect between pre-operative imaging parameters and long-term clinical success. While mechanical stability metrics like insertion torque and resonance frequency analysis are heavily documented [6,7], imaging-derived cortical measurements are rarely tested as independent, predictive variables.

An additional concern involves ethical and interpretive uncertainty. Radiation justification and dose optimization have received considerable attention within CBCT guideline literature [22–33]. However, comparatively little attention has been directed toward interpretive responsibility, uncertainty communication, or ethical implications of radiological overconfidence in cortical implant planning.

Accordingly, this PRISMA 2020-guided critical review aimed to evaluate whether contemporary implant imaging literature genuinely supports reproducible and ethically defensible cortical anchorage planning or whether substantial conceptual, methodological, and professional gaps remain unresolved.

2. Methods

2.1 Protocol and Reporting Standard

This review was conducted and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) statement.

A review protocol defining eligibility criteria, search methodology, screening process, and qualitative synthesis approach was established a priori.

The review protocol was not prospectively registered in PROSPERO because the study was designed as a qualitative, gap-oriented critical synthesis without planned meta-analysis or patient-level interventional outcome pooling.

2.2 Eligibility Criteria

Inclusion Criteria

Studies meeting the following criteria were included:

- Indexed and peer-reviewed publications
- Human clinical studies, observational studies, consensus statements, guideline documents, and systematic reviews
- Literature addressing orthopantomogram (OPG) and/or cone beam computed tomography (CBCT) in dental implant imaging
- Studies evaluating cortical bone assessment, implant stability, radiological reporting approaches, imaging-based implant planning, or ethical considerations in implant imaging
- English-language publications

Exclusion Criteria

The following were excluded:

- Non-indexed or non-peer-reviewed literature
- Animal studies or in-vitro investigations lacking direct clinical applicability
- Case reports or case series without analytical radiological interpretation
- Surgical technique papers without imaging-based decision analysis
- Narrative reviews lacking specific relevance to cortical anchorage imaging
- Studies unrelated to implant imaging or cortical assessment

2.3 Information Sources and Search Period

Electronic literature searches were conducted in the following databases:

- PubMed/MEDLINE
- Scopus
- Cochrane Library

The search period extended from January 2000 to March 2026.

Implant Imaging for Cortical Anchorage: A PRISMA-Guided Critical Review of OPG and CBCT Literature

Additional records were identified through manual screening of reference lists from relevant reviews, consensus statements, and guideline documents [13,22,23].

2.4 Search Strategy

Search strategies were developed using combinations of Medical Subject Headings (MeSH) terms and free-text keywords combined with Boolean operators.

A representative PubMed search strategy was as follows:

("cone beam computed tomography" OR CBCT OR "panoramic radiography" OR orthopantomogram) AND ("dental implant" OR implantology OR "implant planning") AND (cortical OR corticobasal OR basal OR "cortical anchorage") AND ("implant stability" OR "bone quality" OR "oral radiology")

Additional keywords included:

- "radiation justification"
- "implant trajectory"
- "cortical bone thickness"
- "implant imaging"
- "ethical considerations"

2.5 Study Selection

All retrieved records were exported into a reference management system, and duplicate records were removed.

Two independent reviewers performed title and abstract screening according to predefined eligibility criteria. Full-text assessment was subsequently conducted for potentially eligible studies. Disagreements during screening and eligibility assessment were resolved through consensus discussion.

The database search yielded 812 records.

- PubMed/MEDLINE: 368 records
- Scopus: 392 records
- Cochrane Library: 52 records
- Additional records identified through manual search: 24 records

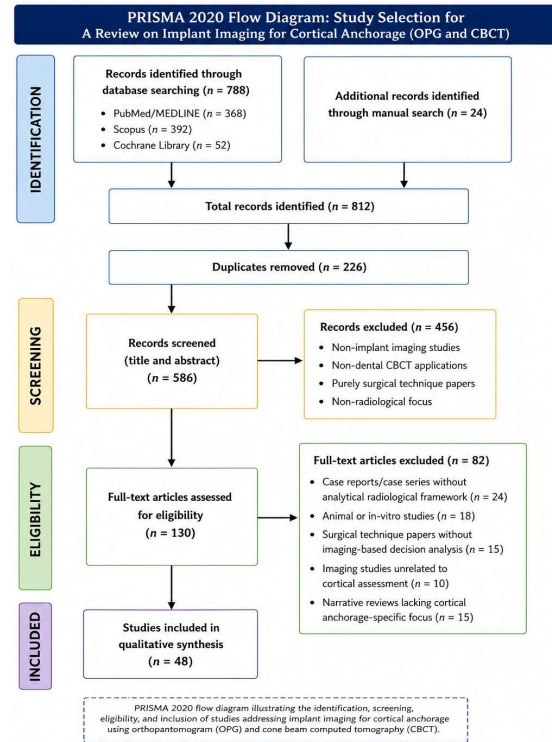
After removal of 226 duplicate records, 586 unique records underwent title and abstract screening.

Subsequently:

- 456 records were excluded after title and abstract screening
- 130 full-text articles were assessed for eligibility
- 82 studies were excluded after full-text assessment
- 48 studies met eligibility criteria and were included in qualitative synthesis

The study selection process is illustrated in the PRISMA 2020 flow diagram.

Fig. 1: PRISMA 2020 FLOW DIAGRAM



2.6 Quality Appraisal

Given the heterogeneity of included study designs, formal meta-analysis was not feasible.

Methodological appraisal primarily focused on:

- Imaging methodology transparency
- Definition of cortical assessment parameters
- Correlation between imaging findings and clinical outcomes
- Reproducibility of radiological interpretation
- Ethical and reporting considerations

2.7 Data Extraction and Qualitative Synthesis

Extracted data included:

- Imaging modality
- Cortical assessment approach
- Reporting parameters
- Implant stability correlations
- Imaging limitations
- Ethical considerations
- Outcome linkage

Due to substantial heterogeneity in study design, imaging methodology, outcome variables, and reporting standards, quantitative synthesis was not appropriate. Therefore, a qualitative, gap-oriented narrative synthesis was performed.

3. Results

3.1 Study Selection

Following full-text assessment, 82 indexed articles were excluded.

The most frequent reasons for exclusion included:

- Case reports or case series lacking analytical radiological frameworks

Implant Imaging for Cortical Anchorage: A PRISMA-Guided Critical Review of OPG and CBCT Literature

- Animal or in-vitro study designs without clinical CBCT applicability
 - Surgical technique papers without imaging-based decision analysis
 - Imaging studies unrelated to implant planning or cortical assessment
 - Narrative reviews lacking cortical anchorage-specific focus
- Representative excluded studies and reasons for exclusion are summarized in Supplementary Table S1.

Supplementary Table S1. Representative Excluded Studies and Reasons for Exclusion

<i>S</i> <i>L</i> <i>N</i> <i>o.</i>	First Author	Year	Journal	Study Focus	Reason for Exclusion
1	Balshin TJ	2001	Int J Oral Maxillofac Implants	Immediate loading in mandible	Case series; imaging descriptive only without analytical radiological framework
2	Malo P	2005	Clin Implant Dent Relat Res	All-on-4 protocol	Surgical-prosthetic focus; imaging not analyzed as independent decision variable
3	Krekmanov L	2000	Clin Oral Implants Res	Tilted implant placement	Imaging used illustratively without cortical or trajectory-based

					analysis
4	Trisi P	2009	Int J Oral Maxillofac Implants	Bone-implant contact studies	Animal study lacking direct clinical CBCT applicability
5	Seong WJ	2009	Clin Oral Implants Res	Implant stability in bone blocks	In-vitro design without clinical radiological interpretation
6	Ihde S	2010	Implant Dent	Cortico basal implant concepts	Technique-driven narrative without analytical imaging methodology
7	Scortecchi G	1999	J Oral Implantol	Basal implant techniques	Surgical technique paper without radiological decision analysis
8	Ludlow JB	2006	Dentomaxillofac Radiol	CBCT dosimetry	Radiation physics focus unrelated to implant decision-

Implant Imaging for Cortical Anchorage: A PRISMA-Guided Critical Review of OPG and CBCT Literature

					making
9	Farnan AG	2008	Oral Surg Oral Med Oral Pathol Oral Radiol Endod	CBCT principles	General imaging overview not specific to implant cortical assessment
10	Bornstein MM	2017	Periodontol 2000	Imaging in implant dentistry	Broad descriptive review lacking cortical anchorage-specific analysis
11	Jacobs R	2018	Clin Oral Investig	CBCT in dentistry	Descriptive review without outcome-linked cortical framework
12	Naitoh M	2010	Oral Surg Oral Med Oral Pathol Oral Radiol Endod	Mandibular canal morphology	Anatomical study without implant planning correlation
13	Chan HL	2010	J Periodontol	Mandibular anatomy	Imaging descriptive; cortical

					anchorage not specifically addressed
14	Greenstein G	2006	J Periodontol	Mental foramen anatomy	Risk discussion only without cortical implant framework
15	Esposito M	2014	Cochrane Database Syst Rev	Implant survival outcomes	Outcome-focused review without imaging parameter analysis
16	Lindhe J	2008	J Clin Periodontol	Peri-implant disease	Biological focus; imaging not evaluated analytically
17	Dawood A	2009	Br Dent J	CBCT in clinical practice	General review lacking cortical trajectory analysis
18	Horne R K	2009	Dentomaxillofac Radiol	CBCT principles and guidelines	Guideline-focused discussion without

Implant Imaging for Cortical Anchorage: A PRISMA-Guided Critical Review of OPG and CBCT Literature

					t cortical anchorage framework
19	Guerreiro ME	2014	Clin Oral Implants Res	CBCT risk assessment	Conventional implant planning focus without cortical engagement analysis
20	Chan HL	2014	Implant Dent	Implant complications	Imaging secondary to surgical outcome discussion
21	Tyndall DA	2008	Dent Clin North Am	CBCT applications	Broad CBCT applications review without cortical implant specificity
22	Scarfe WC	2006	J Can Dent Assoc	Clinical applications of CBCT	General radiology review without implant outcome linkage

23	Loubele M	2008	Dentomaxillofac Radiol	Linear measurement accuracy	Technical validation study without cortical planning implications
24	Hassan B	2010	Clin Oral Investig	CBCT linear accuracy	Technical measurement study lacking implant stability correlation
25	Pauwels R	2013	Dentomaxillofac Radiol	CBCT grey values	Technical density variability analysis without cortical anchorage outcome assessment
26	Nackers O	2011	Clin Oral Implants Res	Intensity variability in CBCT	Technical imaging study without clinical cortical planning framework

Implant Imaging for Cortical Anchorage: A PRISMA-Guided Critical Review of OPG and CBCT Literature

27	Nomura Y	2013	Int J Oral Maxillofac Implants	Reliability of voxel values	Density evaluation study without implant trajectory analysis					radiological framework
28	Greenstein G	2008	J Periodontol	Implant surgical anatomy	Anatomical review without imaging-based cortical assessment					Navigation-focused study without cortical assessment parameters
29	Misch CE	2008	Dent Today	Bone density concepts	Narrative discussion without radiological methodology					Surgical navigation study unrelated to cortical suitability definitions
30	Bedrossian E	2012	Implant Dent	Zygomatic and remote anchorage concepts	Primarily surgical discussion without structured imaging analysis					Guideline paper without implant-specific cortical analysis
31	Aparicio C	2014	Clin Implant Dent Relat Res	Tilted implants and immediate loading	Prosthetic-surgical emphasis without analytical					Technical imaging validation lacking outcome-oriented cortical analysis
32	Cassata M	2012	Implant Dent							Surgical guide accuracy
33	Vercruyssen M	2014	Clin Oral Implants Res							Guided surgery accuracy
34	Dulak	2014	Dentomaxillofac Radiol							CBCT indications
35	Benic GI	2013	Int J Oral Maxillofac Implants							Dimensional accuracy of CBCT

Implant Imaging for Cortical Anchorage: A PRISMA-Guided Critical Review of OPG and CBCT Literature

36	Van Assche N	2012	Clin Oral Implants Res	Computer-assisted implant planning	Surgical workflow emphasis without cortical radiological interpretation
37	Suomalainen A	2015	Oral Surg Oral Med Oral Pathol Oral Radiol	CBCT radiation dose	Radiation-focused study without implant planning analysis
38	Guerreiro ME	2006	Dentomaxillofac Radiol	Preoperative implant imaging	General implant imaging review lacking cortical anchorage specificity
39	Tahmaseb A	2014	Clin Oral Implants Res	Computer-guided surgery	Surgical planning emphasis without cortical trajectory framework
40	Bornstein MM	2019	Periodontol 2000	Contemporary	Consensus-focused
					implant imaging narrative lacking gap-oriented cortical analysis
41	Tadina da A	2015	Oral Surg Oral Med Oral Pathol Oral Radiol		CBCT artifact assessment without cortical implant implications
42	Kaasalainen T	2021	Phys Med		Physical principles of CBCT discussion without implant outcome correlation
43	Li G	2013	Imaging Sci Dent		Radiation dose in CBCT without cortical assessment analysis
44	O'Malley L	2015	Dentomaxillofac Radiol		Radiation protection guideline-oriented review without implant-

Implant Imaging for Cortical Anchorage: A PRISMA-Guided Critical Review of OPG and CBCT Literature

					specific cortical framework
45	Berkhout WE	2015	Dentomaxillofac Radiol	Ethical aspects of dental radiology	Broad ethical review without cortical implant planning specificity
46	Berlin L	2005	AJR Am J Roentgenol	Errors of omission	General radiology cognition paper without implant imaging specificity
47	Croskerry P	2009	Acad Med	Diagnostic cognitive bias	General diagnostic reasoning paper not specific to implant radiology
48	Naitoh M	2010	Oral Surg Oral Med Oral Pathol Oral Radiol Endod	Mandibular canal morphology	Anatomical imaging study lacking implant stability

					linkage
49	Loubele M	2009	Eur J Radiol	CBCT versus MSCT radiation dose	Radiation comparison study unrelated to cortical planning
50	Scarfe WC	2008	Dent Clin North Am	CBCT technology overview	Technology-focused review lacking cortical anchorage framework

3.2 Absence of Radiological Definitions of Cortical Suitability

Across included studies, cortical bone was repeatedly identified as a determinant of implant stability without operational radiological definition. Associations between cortical thickness and primary implant stability have been reported [6–10], yet no included study established validated radiological thresholds applicable across implant designs, loading protocols, or anatomical regions.

Radiological descriptions frequently remained qualitative, relying on terms such as “dense cortical support” or “adequate cortical engagement” without reproducible measurement standards.

This absence of standardized definitions limits interobserver reproducibility and contributes to continued dependence on operator experience.

Identified Gap

Absence of validated, trajectory-specific radiological definitions of cortical suitability.

3.3 Panoramic Radiography: Continued Use Without Validated Boundaries

Although panoramic radiography remains a routine preliminary screening tool due to its accessibility and low radiation dose [11,12], its diagnostic value for cortical anchorage is severely restricted. Inherent geometric distortion, unpredictable magnification, structural superimposition, and the complete absence of a buccolingual perspective compromise accurate trajectory planning [11–13]. While contemporary radiological guidelines advocate for

CBCT in anatomically complex scenarios [13,22,23], the current literature fails to establish strict diagnostic boundaries that define exactly when panoramic imaging suffices and when three-dimensional assessment becomes an absolute requirement for cortical stabilization.

3.4 CBCT: Accuracy Without Cortical-Specific Standardization

CBCT provides exceptional three-dimensional spatial visualization [14–18,22–24]; however, standard imaging protocols are optimized for traditional endosseous placement rather than targeted cortical engagement. Routine software evaluations prioritize static orthogonal dimensions, focusing on crest-to-canal distances or standardized ridge widths. These traditional metrics are insufficient for planning oblique trajectories, verifying multi-cortical continuity, or assessing remote basal stabilization. Compounding this issue is the stark methodological inconsistency in how cortical thickness is reported across studies, with measurement sites varying arbitrarily between crestal, mid-alveolar, and basal regions. This heterogeneity severely limits the reproducibility of trajectory-based cortical assessments.

3.5 CBCT Gray Values and the Persistent Density Dilemma

The use of CBCT gray values to estimate bone density remains controversial [19–21,23,24]. Because these values are highly susceptible to device calibration, scatter radiation, varied voxel sizes, and proprietary reconstruction algorithms, they do not correlate reliably with true Hounsfield Units. Nevertheless, subjective terminology—such as "dense cortical bone" or "poor density"—continues to dominate clinical imaging reports. This reliance on non-standardized qualitative descriptors introduces significant predictive uncertainty, as no current studies have successfully established universal gray-value thresholds capable of guaranteeing cortical anchorage across different implant systems.

3.6 Imaging–Outcome Disconnect

Although implant stability and survival outcomes are extensively discussed in implant literature, relatively few studies prospectively linked predefined imaging parameters to long-term clinical outcomes.

Measures such as insertion torque and resonance frequency analysis are frequently employed [6,7]. However, imaging findings are often presented descriptively rather than as independently testable predictive variables.

Cortical thickness, cortical continuity, or trajectory feasibility are rarely predefined as hypotheses to be validated against stability or survival outcomes.

Consequently, imaging frequently functions as explanatory background rather than predictive evidence.

This disconnect contributes to continued dependence on clinical intuition and operator experience.

Identified Gap

Lack of prospective, outcome-oriented studies validating imaging-derived cortical parameters as predictors of implant stability and long-term success.

3.7 Ethical and Professional Gaps Beyond Radiation Dose

Radiation optimization and justification are extensively addressed within CBCT guideline literature [25–33].

However, ethical considerations in implant imaging extend beyond radiation exposure alone.

Interpretation itself carries ethical and medico-legal responsibility.

Across included studies, comparatively little attention was directed toward:

- Interpretive uncertainty
 - Confidence disclosure
 - Probabilistic reporting
 - Communication of imaging limitations
 - Ethical implications of radiological overconfidence
- This issue becomes particularly relevant in cortical implantology where imaging may be used to justify unconventional implant trajectories, immediate loading protocols, or engagement of remote cortical structures.

When uncertainty is not explicitly acknowledged, clinicians may overestimate the predictive capability of imaging findings and patients may provide consent under assumptions of certainty unsupported by evidence.

Identified Gap

Underdeveloped ethical frameworks addressing interpretive uncertainty, responsibility, and communication in implant imaging.

4. Discussion

This PRISMA-guided critical review demonstrates that although implant imaging technology has advanced substantially, conceptual and methodological frameworks guiding its use in cortical implantology remain incompletely developed.

Panoramic radiography continues to be used despite recognized limitations and absence of validated cortical planning thresholds [11–13].

CBCT provides accurate three-dimensional anatomical visualization [14–18]; however, standardized cortical-specific assessment frameworks remain lacking [22–24].

Importantly, the review identified a recurring disconnect between imaging-derived parameters and validated clinical outcomes.

Cortical parameters are frequently described but rarely prospectively validated as predictors of implant stability or long-term success.

This contributes to persistent reliance on operator experience rather than reproducible evidence-based interpretation.

An important unresolved issue identified in this review is the absence of trajectory-oriented radiological frameworks specifically designed for cortical anchorage.

Conventional implant imaging protocols primarily rely on static orthogonal measurements, whereas cortical implantology frequently depends on dynamic multi-cortical engagement extending beyond conventional crestal trajectories.

This discrepancy may partly explain why advanced imaging technology has not entirely eliminated interpretive uncertainty in cortical implant planning. From a radiological perspective, this creates professional ambiguity.

Radiologists are frequently expected to comment on cortical suitability despite absence of universally validated criteria [48]. Consequently, reporting often remains cautious yet imprecise.

Surgeons, in turn, depend substantially on experiential judgment to bridge evidentiary gaps.

Cognitive and Interpretive Considerations

The physical limitations of radiological hardware are frequently compounded by cognitive biases during image interpretation. Classic diagnostic pitfalls—such as anchoring effects, heuristic reasoning, and premature diagnostic closure—are well-documented in the broader medical radiology literature [41,42]. Within cortical implantology, these cognitive vulnerabilities become pronounced when clinicians attempt to mentally extrapolate primary mechanical stability from static, two-dimensional radiological appearances. This subjective, experience-based reliance highlights the urgent clinical need to transition toward objective, standardized reporting frameworks that minimize diagnostic heuristics.

4.1 Clinical Implications

The findings of this review suggest that contemporary imaging practices support cortical implant planning more through accumulated experience than through structured predictive evidence.

While this does not invalidate successful clinical outcomes, it highlights vulnerability to variability, inconsistency, and interpretive overconfidence.

Standardized CBCT reporting frameworks incorporating:

- Trajectory analysis
 - Cortical continuity assessment
 - Confidence statements
 - Structured uncertainty disclosure
- may improve reproducibility and interdisciplinary communication.

4.2 Future Research Directions

Future research should prioritize clinically translatable outcome-oriented frameworks rather than purely descriptive imaging analysis.

Particularly important areas include:

- Prospective studies correlating imaging-derived cortical parameters with implant stability and survival outcomes
- Interobserver reliability studies focused on cortical assessment reproducibility
- Trajectory-oriented cortical mapping methodologies
- Ethical analyses addressing uncertainty communication and interpretive responsibility
- AI-assisted predictive modeling integrating CBCT-derived cortical parameters

Trajectory-based cortical continuity mapping and probabilistic risk estimation may represent promising future directions for improving predictive implant imaging.. **Limitations**

This review has several limitations.

First, included studies demonstrated substantial heterogeneity regarding imaging methodology, anatomical assessment criteria, implant systems, and clinical endpoints.

Second, randomized controlled trials specifically addressing cortical implant imaging remain limited. Third, because of methodological heterogeneity and conceptual variability, quantitative synthesis and meta-analysis were not feasible.

Finally, portions of cortical implantology literature remain technique-driven and experience-based, limiting availability of standardized radiological evidence.

Nevertheless, qualitative critical synthesis remained appropriate for identifying unresolved conceptual and methodological gaps within implant imaging literature.

6. Conclusions

While OPG and CBCT are indispensable for general implant dentistry, the current literature lacks a validated, standardized framework specific to cortical anchorage planning. The persistent reliance on subjective definitions of cortical suitability, the absence of dynamic trajectory-based CBCT protocols, and the weak correlation between preoperative imaging and post-operative stability all demand immediate research attention. Moving forward, oral radiology must transition from providing descriptive anatomical overviews to developing objective, predictive measurement protocols that directly inform and validate surgical execution.

REFERENCES

1. Brånemark PI, Zarb GA, Albrektsson T. Tissue-integrated prostheses: osseointegration in clinical dentistry. Chicago: Quintessence Publishing Co; 1985.
2. Albrektsson T, Sennerby L. State of the art in oral implants. J Clin Periodontol. 1991;18(6):474-481.

Implant Imaging for Cortical Anchorage: A PRISMA-Guided Critical Review of OPG and CBCT Literature

- Frost HM. Wolff's Law and bone's structural adaptations to mechanical usage: an overview for clinicians. *Angle Orthod.* 1994;64(3):175-188.
- Frost HM. Bone's mechanostat: a 2003 update. *Anat Rec A Discov Mol Cell Evol Biol.* 2003;275(2):1081-1101.
- Ihde S, Ihde A. Immediate loading of basal implants. *Int J Oral Implantol.* 2009;2(1):7-22.
- Meredith N. Assessment of implant stability as a prognostic determinant. *Clin Oral Implants Res.* 1998;9(2):70-80.
- Sennerby L, Meredith N. Implant stability measurements using resonance frequency analysis. *Clin Oral Implants Res.* 2008;19(7):663-673.
- Miyamoto I, Tsuboi Y, Wada E, Suwa H, Iizuka T. Influence of cortical bone thickness and implant length on implant stability at the time of surgery. *Clin Implant Dent Relat Res.* 2005;7(4):225-231.
- Merheb J, Temmerman A, Rasmusson L, Kübler A, Thor A. Influence of cortical bone thickness on primary implant stability. *Clin Oral Implants Res.* 2010;21(12):1449-1453.
- Turkyilmaz I, McGlumphy EA. Influence of bone density on implant stability parameters and implant success. *J Oral Rehabil.* 2007;34(6):425-431.
- White SC, Pharoah MJ. *Oral radiology: principles and interpretation.* 7th ed. St Louis: Elsevier Mosby; 2014.
- Angelopoulos C. Panoramic radiography: indications, limitations, and clinical utility. *Oral Radiol.* 2013;29(1):1-11.
- Harris D, Horner K, Gröndahl K, Jacobs R, Helmrot E, Benic GI, et al. EAO guidelines for the use of diagnostic imaging in implant dentistry. *Clin Oral Implants Res.* 2012;23(Suppl 5):124-145.
- Scarfe WC, Farman AG. What is cone-beam CT and how does it work? *Dent Clin North Am.* 2008;52(4):707-730.
- Tyndall DA, Rathore S. Cone-beam CT diagnostic applications: caries, periodontal bone assessment, and endodontic applications. *Dent Clin North Am.* 2008;52(4):825-841.
- Guerrero ME, Jacobs R, Loubele M, Schutyser F, Suetens P, van Steenberghe D. State-of-the-art on cone beam CT imaging for preoperative planning of implant placement. *Dentomaxillofac Radiol.* 2006;35(5):309-315.
- Loubele M, Van Assche N, Carpentier K, Maes F, Jacobs R, van Steenberghe D, et al. Comparative localized linear accuracy of small-field cone-beam CT and multislice CT for alveolar bone measurements. *Dentomaxillofac Radiol.* 2008;37(5):252-260.
- Hassan B, van der Stelt P, Sanderink G. Accuracy of linear measurements on cone beam CT images: influence of voxel size and field of view. *Clin Oral Investig.* 2010;14(6):679-686.
- Pauwels R, Nackaerts O, Bellaiche N, Stamatakis H, Tsiklakis K, Walker A, et al. Variability of dental CBCT grey values for density estimations. *Dentomaxillofac Radiol.* 2013;42(8):20120138.
- Nackaerts O, Maes F, Yan H, Couto Souza P, Pauwels R, Jacobs R. Analysis of intensity variability in CBCT images. *Clin Oral Implants Res.* 2011;22(10):1131-1136.
- Nomura Y, Watanabe H, Honda E, Kurabayashi T. Reliability of voxel values from cone-beam computed tomography for assessment of bone density. *Int J Oral Maxillofac Implants.* 2013;28(2):e1-e8.
- Bornstein MM, Scarfe WC, Vaughn VM, Jacobs R. Cone beam computed tomography in implant dentistry: a systematic review focusing on guidelines, indications, and radiation dose risks. *Int J Oral Maxillofac Implants.* 2014;29(Suppl):55-77.
- Jacobs R, Salmon B, Codari M, Hassan B, Bornstein MM. Cone beam computed tomography in implant dentistry: recommendations for clinical use. *Clin Oral Implants Res.* 2018;29(Suppl 16):67-77.
- Dawood A, Patel S, Brown J. Cone beam CT in dental practice. *Br Dent J.* 2009;207(1):23-31.
- Horner K, Islam M, Flygare L, Tsiklakis K, Whaites E. Basic principles for use of dental cone beam computed tomography. *Dentomaxillofac Radiol.* 2009;38(4):187-195.
- Horner K, O'Malley L, Taylor K, Glennly AM. Guidelines for clinical use of CBCT: a review. *Dentomaxillofac Radiol.* 2013;42(1):20120225.
- Scarfe WC, Farman AG, Sukovic P. Clinical applications of cone-beam computed tomography in dental practice. *J Can Dent Assoc.* 2006;72(1):75-80.
- Loubele M, Bogaerts R, Van Dijk E, Pauwels R, Vanheusden S, Suetens P, et al. Comparison between effective radiation dose of CBCT and MSCT scanners for dentomaxillofacial applications. *Eur J Radiol.* 2009;71(3):461-468.
- Li G. Patient radiation dose from dental cone beam computed tomography. *Imaging Sci Dent.* 2013;43(2):63-69.
- International Commission on Radiological Protection. The 2007 recommendations of the International Commission on Radiological Protection. *Ann ICRP.* 2007;37(2-4):1-332.
- European Commission. Radiation Protection No. 172: Cone beam CT for dental and maxillofacial radiology. Luxembourg: Publications Office of the European Union; 2012.
- Berkhout WE, Beuger DA, Sanderink GC, van der Stelt PF. Ethical aspects of dental radiology. *Dentomaxillofac Radiol.* 2015;44(1):20140390.
- O'Malley L, Smith A, Barry S, Patel N, Horner K. Radiation protection and justification of cone beam CT in dental practice. *Dentomaxillofac Radiol.* 2015;44(1):20140230.
- Esposito M, Grusovin MG, Polyzos IP, Felice P, Worthington HV. Interventions for replacing

- missing teeth: dental implants in the edentulous jaw. *Cochrane Database Syst Rev*. 2014;(7):CD003878.
35. Albrektsson T, Dahlin C, Jemt T, Sennerby L, Turri A, Wennerberg A. Is marginal bone loss around oral implants the result of infection? *Clin Implant Dent Relat Res*. 2014;16(6):783-791.
 36. Lindhe J, Meyle J. Peri-implant diseases: consensus report of the Sixth European Workshop on Periodontology. *J Clin Periodontol*. 2008;35(Suppl 8):282-285.
 37. Ihde S, Palka L. Corticobasal implantology: an overview. *Ann Maxillofac Surg*. 2015;5(2):230-235.
 38. Kopp KC, Koslow AH, Abdo OS. Predictable implant placement with corticobasal anchorage. *J Oral Implantol*. 2003;29(5):221-226.
 39. Kaasalainen T, Ekholm M, Siiskonen T, Kortensniemi M. Dental cone-beam CT: physical and technical principles. *Phys Med*. 2021;88:193-217.
 40. Spin-Neto R, Costa C, Salgado DM, Wenzel A. Dose reduction strategies in CBCT for implant dentistry. *Oral Surg Oral Med Oral Pathol Oral Radiol*. 2024;137(2):e1-e12.
 41. Berlin L. Errors of omission. *AJR Am J Roentgenol*. 2005;185(6):1416-1420.
 42. Croskerry P. Diagnostic failure: cognitive and affective biases. *Acad Med*. 2009;84(11):1533-1541.
 43. Greenstein G, Tarnow D. The mental foramen and nerve: clinical and anatomical factors related to dental implant placement. *J Periodontol*. 2006;77(12):2030-2037.
 44. Chan HL, Misch K, Wang HL. Dental imaging in implant therapy. *J Periodontol*. 2010;81(3):388-395.
 45. Bornstein MM, Al-Nawas B, Kuchler U, Tahmaseb A. Consensus statements and recommended clinical procedures regarding contemporary surgical and radiographic techniques in implant dentistry. *Periodontol 2000*. 2019;81(1):241-258.
 46. Naitoh M, Hiraiwa Y, Aimiya H, Gotoh K, Arijji E. Morphometric analysis of mandibular canal using CBCT. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*. 2010;109(1):e25-e30.
 47. Guerrero ME, Jacobs R, Loubele M, Schutyser F, van Steenberghe D. CBCT-based risk assessment in implant dentistry. *Clin Oral Implants Res*. 2014;25(5):e1-e8.
 48. Horner K. The role of the oral and maxillofacial radiologist in dental implant planning. *Br Dent J*. 2015;218(6):343-347.

Implant Imaging for Cortical Anchorage: A PRISMA-Guided Critical Review of OPG and CBCT Literature