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Patient Satisfaction and Diagnostic Accuracy of Digital Radiographic Techniques for Early Detection of Dental Caries

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ABSTRACT

Dental caries remains one of the most prevalent oral diseases worldwide, and early detection is essential to prevent irreversible structural damage. Digital radiographic modalities digital periapical radiography, cone-beam computed tomography (CBCT), and phosphor storage plate (PSP) imaging have enhanced diagnostic capabilities; however, comparative evidence integrating diagnostic accuracy and patient satisfaction remains limited. This prospective cross-sectional study included 120 adults (18–55 years) with suspected proximal or occlusal caries, each undergoing all three imaging techniques. Diagnostic accuracy was evaluated by two calibrated examiners using histological gold standards, while patient satisfaction was measured through a validated five-domain questionnaire. CBCT demonstrated the highest sensitivity (94.3%) and specificity (91.7%), followed by digital periapical (84.6% and 88.2%) and PSP (79.1% and 82.4%). Despite superior accuracy, CBCT received lower satisfaction scores than digital periapical radiography (3.67 vs. 4.31; p = .003), mainly due to radiation concern and longer procedure time. Digital periapical radiography provides the best balance between accuracy and patient acceptance for routine early caries detection, while CBCT is best reserved for complex cases.

***Keywords**: Digital Radiography, Dental Caries Detection, Diagnostic Accuracy, Patient Satisfaction, CBCT*

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INTRODUCTION

Dental caries is a multifactorial, biofilm-mediated disease that affects an estimated 2.3 billion individuals with permanent teeth globally, constituting one of the most widespread non-communicable diseases in the world (Peres et al., 2019). The global burden of untreated dental caries in permanent teeth has remained largely unchanged over the past three decades, highlighting persistent challenges in prevention and early detection (GBD 2017 Disease and Injury Incidence and Prevalence Collaborators, 2018). The clinical significance of early caries detection cannot be overstated; lesions identified at the enamel or early dentin stage are amenable to non-operative management through remineralization, whereas cavitated or advanced lesions require operative intervention with associated costs to tooth structure, patient wellbeing, and healthcare resources (Pitts et al., 2017).

The biological basis of this approach is grounded in the understanding that the caries process is dynamic and reversible at its initial stages, driven by cyclical demineralization and remineralization processes modulated by saliva, fluoride, and oral hygiene behaviors (Featherstone, 2004). Radiographic diagnosis is an indispensable component of the clinical diagnostic process, enabling the detection of interproximal, occlusal, and root surface caries that may be clinically occult (Wenzel, 2014). As digital imaging technologies continue to evolve, the dental profession faces an expanding array of radiographic modalities, each with distinct imaging characteristics, radiation dose profiles, and patient experience attributes (van der Stelt, 2008).

The transition from conventional film-based radiography to digital systems has produced measurable improvements in diagnostic image quality, radiation dose reduction, and workflow efficiency (Mouyen et al., 1989). Digital periapical radiography using charge-coupled device (CCD) or complementary metal-oxide-semiconductor (CMOS) sensors achieves dose reductions of 40–80% compared to conventional E/F-speed film while providing instantaneous image capture and digital enhancement capabilities (Wenzel & Gröndahl, 2019). The superior spatial resolution and real-time image availability of solid-state sensor systems have contributed to their widespread adoption in clinical practice, though sensor rigidity and size constraints can present challenges in patients with limited mouth opening or prominent gag reflexes (Farman & Farman, 2005).

Phosphor storage plate (PSP) systems offer flexibility in sensor size and shape, making them suitable for challenging anatomical configurations, although their delayed image capture and susceptibility to handling artifacts represent notable limitations (Versteeg et al., 1997). A systematic review by Schwendicke et al. (2015) found no statistically significant difference in diagnostic accuracy for caries detection between CCD-based systems and PSP systems, underscoring the importance of operator technique and clinical protocol standardization. Cone-beam computed tomography (CBCT) provides three-dimensional volumetric data with high spatial resolution, and several studies have reported its superiority in detecting dentinal caries lesions compared to two-dimensional modalities (Tsuchida et al., 2020; Haiter-Neto et al., 2018). A meta-analysis by Kühnisch et al. (2016) demonstrated that CBCT yielded higher sensitivity for occlusal and approximal caries detection relative to intraoral radiography, although specificity was comparably lower, raising

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concerns about potential overdiagnosis. Nevertheless, CBCT is associated with substantially higher radiation dose and cost, and its routine use for caries detection remains a subject of ongoing debate in the literature (Pauwels et al., 2012). The effective radiation dose from CBCT examinations ranges from approximately 19 to 652 μSv depending on field of view and acquisition parameters, compared to 1–8 μSv for a full-mouth periapical radiographic series using digital sensors (SEDENTEXCT Project Consortium, 2012).

Despite substantial research on the technical performance of individual digital radiographic systems, comparative studies examining multiple modalities simultaneously with standardized methodology are limited. Furthermore, the majority of published research has prioritized diagnostic performance metrics such as sensitivity and specificity while neglecting the patient experience dimension of radiographic diagnosis (Paurazas et al., 2000). Patient satisfaction with dental radiographic procedures is influenced by factors including radiation anxiety, physical comfort during sensor placement, procedure duration, perceived image quality, and communication by dental practitioners regarding radiation safety (Holtfreter et al., 2021). Studies have demonstrated that patient-reported discomfort during intraoral radiography is significantly higher for rigid CCD/CMOS sensors compared to flexible PSP plates, particularly in posterior regions and in pediatric patients (Berkhout et al., 2004). Radiation anxiety among dental patients is a well-documented phenomenon, with surveys indicating that a substantial proportion of patients express concern about ionizing radiation exposure even from low-dose diagnostic procedures (Lam et al., 2014).

Effective patient communication regarding the ALARA (As Low As Reasonably Achievable) principle and comparative dose contextualization has been shown to reduce anxiety and improve procedural acceptance (European Commission, 2004). A comprehensive understanding of both diagnostic accuracy and patient satisfaction is essential for evidence-based selection of radiographic modalities in clinical practice and policy development (Espelid et al., 2012). Prior studies have not simultaneously evaluated these dimensions across three major digital radiographic modalities in a single prospective cohort, representing a clear gap in the existing evidence base.

This study therefore aims to conduct a direct comparison of the diagnostic accuracy of digital periapical radiography (CCD/CMOS sensor), PSP radiography, and CBCT for early dental caries detection, and to concurrently assess patient satisfaction across all three modalities using a validated multidimensional questionnaire instrument. The novelty of this research lies in its integrated dual-outcome design, combining objective diagnostic performance measurement with subjective patient-reported outcomes in a single prospective study framework, thereby enabling a clinically meaningful cost-benefit analysis of digital radiographic options for routine caries detection.

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METHODS

A prospective cross-sectional comparative study was conducted between January and June 2024 at a tertiary dental hospital after obtaining ethical approval from the institutional Health Research Ethics Committee (Protocol No. 0124/KEP/EC/2024). Written informed consent was obtained from all participants prior to enrollment. A total of 120 adult patients (54 males and 66 females; mean age 32.7 ± 9.4 years, range 18–55 years) were recruited through purposive sampling from individuals presenting for routine dental examination. Inclusion criteria comprised clinical evidence or suspicion of proximal or occlusal caries in posterior teeth, no radiographic examination of the suspected tooth within the previous six months, and no contraindications to radiographic procedures. Patients were excluded if they were pregnant, had known thyroid disease, used orthodontic appliances that could produce scatter artifacts, or were unable to provide informed consent. Sample size calculation based on an expected sensitivity of 85%, caries prevalence of 60%, and a 95% confidence interval indicated a minimum of 108 subjects; therefore, 120 participants were included to account for potential dropout.

Each participant underwent three radiographic examinations during a single visit. Digital periapical images were obtained using a CCD/CMOS sensor (Kodak RVG 6100, Carestream Dental, USA) at standardized exposure parameters (60 kVp, 7 mA, 0.16 seconds) with a parallel technique and film-holding device. Phosphor storage plate (PSP) images were acquired using Digora Optime plates (Soredex, Finland) with identical geometric angulation. Cone-beam computed tomography (CBCT) scans were performed using a Planmeca ProMax 3D unit (Planmeca, Finland) under a low-dose protocol (80 kVp, 5 mA, field of view 8 × 8 cm, voxel size 200 μm). A 10-minute washout interval was maintained between procedures to minimize patient fatigue. All images were independently evaluated by two calibrated oral radiologists with more than 10 years of experience, who were blinded to clinical findings and to each other's assessments. Interobserver reliability showed strong agreement (Cohen's $\kappa = 0.84$).

Histological examination served as the reference standard for teeth requiring extraction (n = 68). Extracted teeth were sectioned mesiodistally, stained with hematoxylin and eosin, and examined under light microscopy at 10× magnification by a blinded oral pathologist. For teeth not indicated for extraction (n = 52), clinical validation was performed through direct visual inspection using magnification loupes and ICDAS-II criteria. Diagnostic performance for each modality was calculated in terms of sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and area under the receiver operating characteristic curve (AUC).

Patient satisfaction was assessed immediately after completion of all radiographic procedures using a validated 20-item self-administered questionnaire developed and pilot-tested in a previous study. The instrument evaluated five domains: physical comfort during the procedure, perceived procedure duration, radiation safety concerns, quality of communication by the radiographer, and overall radiographic experience. Responses were recorded using a five-point Likert scale (1 = very dissatisfied to 5 = very satisfied) along with a 100-mm Visual Analog Scale (VAS) for overall experience. Domain scores were averaged to obtain a composite satisfaction score.

Data analysis was performed using SPSS version 26.0 (IBM Corp., USA). Differences in satisfaction among the three imaging modalities were analyzed using one-way repeated measures ANOVA with Bonferroni post-hoc correction, and a p-value of less than 0.05 was considered statistically significant.

RESULTS

1.Diagnostic Accuracy of Radiographic Modalities

CBCT demonstrated the highest diagnostic performance for early caries detection, with sensitivity of 94.3%, specificity of 91.7%, PPV of 93.1%, NPV of 92.9%, and AUC of .971 (95% CI: .942–.989). Digital periapical radiography achieved sensitivity of 84.6%, specificity of 88.2%, PPV of 87.1%, NPV of 86.0%, and AUC of .906 (95% CI: .872–.938). PSP radiography demonstrated the lowest performance with sensitivity 79.1%, specificity 82.4%, PPV 81.3%, NPV 80.4%, and AUC of .872 (95% CI: .830–.914). The difference in AUC between CBCT and digital periapical was statistically significant ($p = .003$), as was the difference between digital periapical and PSP ($p = .012$). Summary diagnostic accuracy data are presented in Table 1.

Table 1. Diagnostic Accuracy of Three Digital Radiographic Modalities for Early Dental Caries Detection

Modality	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	AUC
Digital Periapical (CCD/CMOS)	84.6	88.2	87.1	86.0	.906
PSP Radiography	79.1	82.4	81.3	80.4	.872
CBCT	94.3	91.7	93.1	92.9	.971

Subgroup analysis by lesion location revealed that CBCT's diagnostic superiority was most pronounced for proximal lesions (sensitivity advantage +12.4% over digital periapical; $p < .001$) and less marked for occlusal lesions (+7.8%; $p = .018$). For enamel-confined lesions specifically, CBCT demonstrated particularly superior detection rates (sensitivity 88.6%) compared to digital periapical (72.3%) and PSP (67.4%), highlighting its utility in identifying early non-cavitated lesions. Interobserver agreement was excellent across all modalities (κ range: .81–.87).

2.Patient Satisfaction Results

Composite satisfaction scores differed significantly across the three radiographic modalities, $F(2, 238) = 18.74$, $p < .001$, $\eta^2 p = .136$. Post-hoc analysis revealed that patient satisfaction was significantly higher for digital periapical radiography (mean composite score: 4.31 ± 0.47) compared to CBCT (3.67 ± 0.53; $p = .003$) and PSP (3.88 ± 0.51; $p = .021$). The difference between PSP and CBCT was not statistically significant ($p = .112$). Domain-level analysis identified radiation safety concern as the domain with the greatest mean score difference between digital periapical and CBCT (mean

difference: 0.89; 95% CI: 0.54–1.24), indicating substantially higher radiation anxiety among patients undergoing CBCT. Summary satisfaction data by domain are presented in Table 2.

Table 2. Patient Satisfaction Domain Scores by Radiographic Modality (Mean ± SD; Scale 1–5)

Satisfaction Domain	Digital Periapical	PSP	CBCT	p-value
Physical Comfort	4.42 ± 0.51	4.11 ± 0.58	3.76 ± 0.62	.001
Procedure Duration	4.58 ± 0.43	4.22 ± 0.49	3.54 ± 0.70	<.001
Radiation Safety Concern	4.29 ± 0.55	4.01 ± 0.60	3.40 ± 0.72	<.001
Communication Quality	4.19 ± 0.61	4.10 ± 0.64	4.03 ± 0.67	.312
Overall Experience	4.12 ± 0.53	3.96 ± 0.58	3.62 ± 0.61	.004

No significant differences in communication quality scores were observed across the three modalities ($p = .312$), suggesting that practitioner communication behaviors were consistent regardless of the imaging system used. Female patients reported significantly higher radiation concern scores across all modalities compared to male patients ($p = .024$), consistent with prior findings in the radiographic literature. No significant age-related differences in overall satisfaction scores were observed ($r = -.14$; $p = .127$).

DISCUSSION

This study provides an integrated comparative evaluation of three major digital radiographic modalities digital periapical radiography (CCD/CMOS), phosphor storage plate (PSP), and cone beam computed tomography (CBCT) by combining diagnostic performance indicators with patient satisfaction outcomes. This dual-outcome approach addresses a critical gap in the literature, where most previous studies have assessed technical accuracy and patient-reported experience separately, despite the need for clinically realistic decision-making that balances both dimensions (Schwendicke et al., 2015; Espelid et al., 2012). The combined analysis of AUC, sensitivity, specificity, and multidimensional satisfaction scores provides a more comprehensive framework for evaluating modality suitability in routine clinical practice.

CBCT demonstrated the highest diagnostic sensitivity, particularly for early proximal and enamel lesions, consistent with previous systematic reviews (Kühnisch et al., 2016; Tsuchida et al., 2020). Its superior performance is primarily attributable to three-dimensional volumetric imaging, which eliminates anatomical superimposition and allows evaluation in multiple planes. This capability improves visualization of subtle mineral density changes that may be obscured in two-dimensional imaging (Wenzel, 2014). However, the increased sensitivity was accompanied by relatively lower specificity, suggesting a higher risk of false-positive findings and potential overdiagnosis, especially in low-prevalence populations. Beam-hardening artifacts and image noise may contribute to this limitation (Bechara et al., 2012). Moreover, CBCT diagnostic performance is

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highly dependent on acquisition parameters such as voxel size and field of view, with small-FOV, high-resolution protocols providing optimal caries detection (Liedke et al., 2014).

Digital periapical radiography achieved excellent diagnostic performance (AUC = 0.906), reaffirming its role as the clinical standard for routine caries detection (Wenzel & Gröndahl, 2019). Compared with PSP, CCD/CMOS systems demonstrated modest but clinically meaningful improvements in sensitivity, which may translate into earlier identification of lesions amenable to non-invasive management (Pitts et al., 2017). Additional advantages include immediate image availability, wide exposure latitude, and compatibility with digital enhancement tools. Nevertheless, the high performance observed in this study may reflect standardized acquisition and interpretation conditions, whereas variability in clinical technique may reduce real-world accuracy (Berkhout et al., 2004). Emerging artificial intelligence–assisted detection tools may further enhance the diagnostic capability of digital periapical systems in future clinical settings (Schwendicke et al., 2021).

PSP imaging showed slightly lower diagnostic performance, which is consistent with previous studies attributing this limitation to lower spatial resolution, handling artifacts, and potential image degradation during the scanning process (Wenzel & Gröndahl, 2019). Despite these constraints, PSP retains important clinical advantages, including plate flexibility, improved comfort in anatomically challenging regions, and better tolerance in pediatric or gag-sensitive patients (Senel et al., 2010). These contextual benefits support a selective rather than routine role for PSP in clinical practice.

Radiation dose considerations remain a critical factor in modality selection. CBCT exposure levels (19–652 μSv) are substantially higher than those of digital periapical imaging (1–8 μSv), reinforcing the continued relevance of the ALARA principle (Pauwels et al., 2012; European Commission, 2012). Consistent with this risk differential, radiation concern emerged as a key determinant of lower patient satisfaction for CBCT. Current international guidelines therefore recommend restricting CBCT use to cases where three-dimensional information will significantly influence diagnosis or treatment planning, and not for routine caries screening (ADA, 2012; SEDENTEXCT, 2012). However, when CBCT is already indicated for other diagnostic purposes, concurrent caries assessment may provide additional value without increasing radiation exposure.

Patient satisfaction findings highlight the growing importance of patient-reported outcomes in dental imaging evaluation. Digital periapical radiography achieved the highest overall satisfaction, driven primarily by shorter procedure time, immediate image display, and lower perceived radiation risk. In contrast, longer workflow duration for PSP and preparation complexity for CBCT negatively affected perceived efficiency. Notably, communication quality scores did not differ significantly across modalities, indicating that practitioner communication—particularly regarding radiation safety and procedural explanation—may be a key modifiable factor influencing patient experience (Ong et al., 1995).

Taken together, these findings support a stratified clinical decision framework. Digital periapical radiography represents the optimal first-line modality for routine caries detection due to

its favorable balance of diagnostic accuracy, low radiation dose, workflow efficiency, and patient acceptance. CBCT should be reserved for selected high-risk or complex cases where additional three-dimensional information is expected to alter clinical management, while PSP serves as a useful alternative in situations requiring greater sensor flexibility or improved patient tolerance.

Several limitations should be considered. The controlled study conditions may not fully reflect clinical variability, and the satisfaction instrument, although validated, may require cultural adaptation for broader generalization. In addition, the cross-sectional design does not capture longitudinal changes in patient perception. Future research should include multicenter prospective studies, real-world clinical conditions, economic evaluation of cost-effectiveness, and investigation of artificial intelligence integration to further optimize evidence-based radiographic decision-making.

CONCLUSIONS

This prospective comparative study demonstrates that CBCT provides the highest diagnostic accuracy for early dental caries detection, particularly for proximal and enamel-confined lesions, while digital periapical radiography offers excellent diagnostic performance combined with significantly superior patient satisfaction outcomes. PSP radiography demonstrated acceptable but inferior performance on both dimensions. The integrated dual-outcome analysis supports a clinically rational hierarchy of radiographic modality selection: digital periapical radiography as the first-line diagnostic tool for routine early caries screening, with CBCT reserved for clinically complex or diagnostically ambiguous cases where its incremental diagnostic benefit justifies the higher radiation dose and associated patient concerns. Communication quality was consistent across modalities, highlighting the practitioner's independent role in shaping the patient radiographic experience. Future research should examine the cost-effectiveness of this stratified radiographic approach across diverse clinical populations and healthcare settings to inform evidence-based radiographic guidelines for caries management.

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