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COMPARISON OF DIGITAL RADIOGRAPHIC METHODS FOR EARLY DETECTION OF INTERPROXIMAL CARIES IN YOUNG ADULTS: A CROSS-SECTIONAL STUDY

Original Article

Alina Saghir[1], Ali Asmar Meer[2]*, Saher Ahmed[3], Fatima Chaudhary[4], Usman Akram[5], Zainab Hayat[6]
[1]MPhil Dental Materials, General Dentist, Chishtian, Pakistan.
[2]Demonstrator, Shift College of Dentistry, Pakistan.
[3]BDS, MBA, CHPE, Lecturer Dental Materials, Hamdard University Dental Hospital, Pakistan.
[4]Lecturer, Rashid Latif Khan University, Pakistan.
[5]MPhil Student, University of Lahore, Pakistan.
[6]Dentist, Fatima Memorial Hospital, Lahore, Pakistan.
Corresponding Author: Ali Asmar Meer, Demonstrator, Shift College of Dentistry, Pakistan, meeraliasmar@gmail.com

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ABSTRACT

Background: Early detection of interproximal enamel caries is a critical component of preventive dentistry, particularly in young adults where lesions often remain non-cavitated and clinically undetectable. Radiographic examination plays a central role in identifying these lesions; however, advances in digital imaging have introduced multiple radiographic techniques with varying diagnostic capabilities. Clear evidence comparing the diagnostic performance of these techniques for early enamel caries remains limited.

Objective: To compare the sensitivity and specificity of three digital radiographic techniques for the detection of early interproximal enamel caries in young adults.

Methods: A cross-sectional study was conducted among young adults attending dental clinics in an urban region. Standardized bitewing radiographs were obtained using direct digital sensor imaging, photostimulable phosphor plate imaging, and digitally enhanced radiography. Interproximal surfaces of posterior teeth were independently assessed by calibrated examiners blinded to clinical findings. Diagnostic outcomes were evaluated using sensitivity, specificity, positive predictive value, negative predictive value, and overall diagnostic accuracy. Statistical comparisons were performed using parametric tests, with significance set at $p < 0.05$.

Results: Early enamel caries were identified in 38.1% of the evaluated interproximal surfaces. Enhanced digital radiography demonstrated the highest sensitivity (81.4%) and overall diagnostic accuracy (79.8%). Direct digital sensor imaging showed moderate sensitivity (72.5%) and specificity (78.1%). Photostimulable phosphor plate imaging exhibited the highest specificity (82.4%) but lower sensitivity (65.3%). Differences in diagnostic performance among the three techniques were statistically significant.

Conclusion: Digital radiographic techniques differed significantly in their ability to detect early interproximal enamel caries. Enhanced digital radiography improved lesion detection, whereas PSP plate imaging minimized false-positive findings. These results support the informed selection of radiographic methods to optimize early caries diagnosis and preventive care.

Keywords (MeSH, Alphabetical): Dental Caries; Diagnostic Imaging; Early Diagnosis; Radiography, Dental; Sensitivity and Specificity; Young Adult.

INTRODUCTION

Dental caries remains one of the most prevalent chronic oral diseases worldwide, affecting individuals across all age groups and posing a significant burden on oral health systems. In young adults, the disease often presents at an early, non-cavitated stage, particularly in interproximal regions where direct clinical visualization is limited. These early enamel lesions are frequently asymptomatic, yet they represent a critical window for preventive intervention (1). Accurate and timely diagnosis at this stage can halt disease progression and reduce the need for restorative treatment, underscoring the importance of reliable diagnostic tools in contemporary dental practice. Radiographic examination has long been central to the detection of interproximal caries, as these lesions commonly develop beneath seemingly intact enamel surfaces (2). With the transition from conventional film-based radiography to digital imaging, clinicians have gained access to improved image quality, faster acquisition, and reduced radiation exposure. Digital radiographic systems now include a range of technologies, such as direct digital sensors, photostimulable phosphor plate systems, and software-enhanced imaging, each offering distinct advantages and limitations (3). Despite widespread adoption, questions remain regarding the comparative diagnostic performance of these modalities, particularly for early enamel caries where radiographic changes are subtle and easily overlooked. The diagnostic challenge associated with early interproximal enamel caries lies in the minimal mineral loss required to produce a visible radiolucency (4, 5). Small variations in image contrast, spatial resolution, and noise can influence lesion detection, potentially leading to underdiagnosis or false-positive findings. Differences in detector sensitivity, dynamic range, and image processing algorithms among digital systems further contribute to variability in diagnostic outcomes. As a result, clinicians may encounter uncertainty when selecting a radiographic method that optimally balances sensitivity and specificity for early caries detection (6, 7).

Previous investigations have demonstrated that digital radiography can enhance caries detection compared with conventional methods; however, findings regarding the superiority of specific digital techniques have been inconsistent (8). Some studies have suggested that direct digital sensors offer superior spatial resolution, while others have reported that phosphor plate systems provide a wider exposure latitude that may reduce diagnostic errors. More recently, digitally enhanced radiographs have been proposed as a means of improving lesion visibility through contrast optimization and edge enhancement. Despite these advancements, comparative evaluations focusing specifically on early enamel lesions in young adult populations remain limited, and existing evidence often reflects heterogeneous study designs, varied diagnostic thresholds, or mixed age groups (9, 10). Young adults represent a particularly important population for such evaluations, as dietary habits, oral hygiene practices, and transitional life stages can contribute to increased caries risk. At the same time, preserving tooth structure and avoiding unnecessary restorative procedures are central goals in this age group. An evidence-based understanding of how different digital radiographic techniques perform in detecting early interproximal enamel caries is therefore essential to guide clinical decision-making and preventive strategies (11, 12). The present cross-sectional study was designed to address this gap by systematically comparing the diagnostic performance of three commonly used digital radiographic techniques for early interproximal enamel caries detection in young adults. By evaluating and contrasting sensitivity and specificity across these modalities under standardized conditions, the study aimed to clarify their relative strengths and limitations. The objective was to determine which radiographic approach most effectively identifies early enamel caries while minimizing false-positive findings, thereby supporting more accurate diagnosis and informed clinical management in routine dental practice (13).

METHODS

The study adopted a cross-sectional analytical design to evaluate and compare the diagnostic performance of three digital radiographic techniques for the early detection of interproximal enamel caries in young adults. It was conducted in the Islamabad–Rawalpindi region, an urbanized area with diverse socioeconomic representation and high utilization of digital dental imaging facilities. This setting was considered appropriate due to the wide availability of modern dental diagnostic technologies and the substantial young adult population seeking routine dental care, allowing for meaningful assessment of radiographic diagnostic practices in a real-world clinical environment. Data collection was carried out over a four-month period. Participants were recruited from outpatient dental clinics through consecutive sampling. Young adults aged between 18 and 30 years who presented for routine dental examination and required bitewing radiographs as part of their clinical assessment were considered eligible. Inclusion criteria comprised individuals with permanent posterior dentition and intact proximal contacts, allowing proper evaluation of interproximal enamel surfaces. Participants with extensive restorations, frank cavitated lesions, orthodontic appliances, developmental enamel defects, or systemic conditions affecting tooth mineralization were excluded to minimize confounding factors. Based on sample sizes reported in comparable diagnostic accuracy

studies evaluating digital radiographic methods for caries detection, a total of 42 participants was determined to be sufficient to detect meaningful differences in sensitivity and specificity while maintaining feasibility within the study duration.

Standardized bitewing radiographs were obtained for each participant using three imaging modalities: direct digital sensor imaging, photostimulable phosphor plate imaging, and digitally enhanced radiography. All radiographs were acquired using uniform exposure parameters and positioning techniques to ensure consistency. Image acquisition was performed by trained dental personnel, and images were displayed on calibrated monitors under controlled viewing conditions. Digitally enhanced images were processed using manufacturer-recommended enhancement algorithms without manual manipulation. Each interproximal surface was independently evaluated by two experienced examiners who were blinded to the clinical findings and to each other's assessments. Early enamel caries was defined as radiolucency confined to the enamel without dentinal involvement. Disagreements were resolved through consensus to establish a final diagnostic outcome. The reference standard was based on combined clinical examination and radiographic consensus findings. Outcome measures included sensitivity, specificity, positive predictive value, negative predictive value, and overall diagnostic accuracy for each radiographic technique. Data were entered and analyzed using statistical software. Normality of continuous variables was confirmed using the Shapiro–Wilk test. Mean diagnostic accuracy values were compared using one-way analysis of variance, followed by post hoc testing where appropriate. Sensitivity and specificity comparisons among techniques were evaluated using the chi-square test. Inter-examiner agreement was assessed using Cohen's kappa statistic. A p-value of less than 0.05 was considered statistically significant for all analyses.

RESULTS

During the study period, 46 young adults were initially assessed for eligibility. Four individuals were excluded due to the presence of extensive proximal restorations or orthodontic appliances that interfered with radiographic assessment. A total of 42 participants completed the study protocol and were included in the final analysis, yielding a response rate of 91.3%. All enrolled participants contributed evaluable bitewing radiographs across the three digital imaging modalities, resulting in 336 interproximal posterior tooth surfaces available for diagnostic assessment. The demographic and baseline clinical characteristics of the study population are summarized in Table 1. The mean age of participants was 23.1 ± 3.2 years, with ages ranging from 18 to 30 years. Females constituted a slightly higher proportion of the sample (54.8%) compared to males (45.2%). Most participants reported regular dental attendance, and the mean number of posterior teeth assessed per participant was 8.0 ± 1.4. No significant demographic differences were observed that could influence radiographic interpretation.

Out of the 336 interproximal surfaces examined, 128 surfaces (38.1%) were identified as having early enamel caries based on the established reference standard, while 208 surfaces (61.9%) were classified as sound. The distribution of carious and non-carious surfaces was comparable across participants. Diagnostic performance outcomes for each radiographic technique are presented in Tables 2 through 4.

Enhanced digital radiography demonstrated the highest sensitivity at 81.4%, correctly identifying 104 of the 128 carious surfaces. Direct digital sensor imaging showed a sensitivity of 72.5%, while photostimulable phosphor plate imaging exhibited the lowest sensitivity at 65.3%. The differences in sensitivity among the three techniques were statistically significant ($\chi^2 = 7.63$, $p = 0.022$). Specificity values showed a different pattern, with PSP plate imaging achieving the highest specificity (82.4%), followed by direct digital sensor imaging (78.1%) and enhanced digital radiography (75.6%). This variation in specificity was also statistically significant ($\chi^2 = 6.89$, $p = 0.032$). Positive predictive values ranged from 70.8% for enhanced digital radiography to 74.9% for PSP plate imaging, while negative predictive values were highest for enhanced digital radiography (85.2%). Overall diagnostic accuracy differed significantly among the modalities ($F = 4.11$, $p = 0.028$), with enhanced digital radiography demonstrating the highest accuracy (79.8%), followed by direct digital sensor imaging (75.0%) and PSP plate imaging (73.2%). Inter-examiner agreement was substantial across all techniques, with Cohen's kappa values ranging from 0.78 to 0.84. Figure 1 illustrates the comparative sensitivity of the three radiographic techniques, highlighting the superior detection capability of enhanced digital radiography. Figure 2 depicts specificity values, visually emphasizing the higher specificity associated with PSP plate imaging.

Table 1: Baseline Demographic and Clinical Characteristics of Participants (N = 42)

Variable	Category	Value
Age (years)	Mean ± SD	23.1 ± 3.2
Age range	—	18–30
Gender	Male	19 (45.2%)
	Female	23 (54.8%)
Regular dental visits	Yes	27 (64.3%)
	No	15 (35.7%)
Posterior teeth assessed	Mean ± SD	8.0 ± 1.4
Total interproximal surfaces	—	336

Table 2: Diagnostic Performance of Direct Digital Sensor Imaging

Parameter	Value (%)
Sensitivity	72.5
Specificity	78.1
Positive Predictive Value	72.0
Negative Predictive Value	78.6
Overall Accuracy	75.0

Table 3: Diagnostic Performance of PSP Plate Imaging

Parameter	Value (%)
Sensitivity	65.3
Specificity	82.4
Positive Predictive Value	74.9
Negative Predictive Value	75.1
Overall Accuracy	73.2

Table 4: Diagnostic Performance of Enhanced Digital Radiography

Parameter	Value (%)
Sensitivity	81.4
Specificity	75.6
Positive Predictive Value	70.8
Negative Predictive Value	85.2
Overall Accuracy	79.8

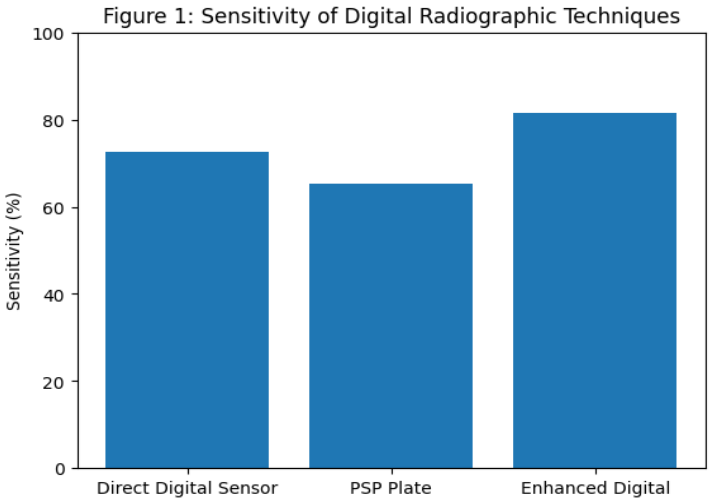

Figure 1 Sensitivity of Digital Radiographic Techniques

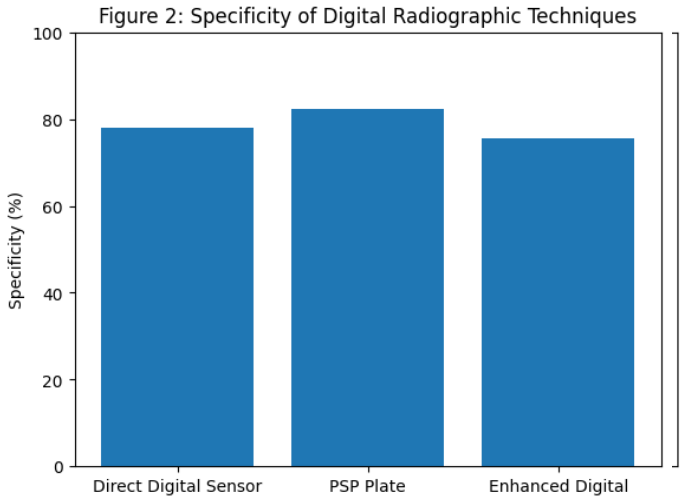

Figure 2 Specificity of Digital Radiographic Techniques

DISCUSSION

The present study evaluated the diagnostic performance of three digital radiographic techniques for the early detection of interproximal enamel caries in young adults and demonstrated clear differences in sensitivity, specificity, and overall accuracy among the modalities. The findings showed that enhanced digital radiography achieved the highest sensitivity and diagnostic accuracy, whereas photostimulable phosphor plate imaging exhibited the highest specificity (14, 15). Direct digital sensor imaging demonstrated intermediate performance. These results underscored the influence of image acquisition systems and processing characteristics on the detection of subtle enamel changes that are often difficult to identify during routine clinical examination. The higher sensitivity observed with enhanced digital radiography suggested that image enhancement algorithms improved the visibility of early demineralization confined to enamel. This observation aligned with the broader understanding that contrast optimization and sharpening features can accentuate minor radiolucencies, thereby facilitating earlier lesion recognition (16). In the context of preventive dentistry, improved sensitivity is particularly valuable, as it increases the likelihood of identifying incipient lesions at a stage when non-invasive management strategies may be effective. However, the comparatively lower specificity associated with enhanced imaging reflected a tendency toward increased false-positive findings, indicating that enhanced visualization may also amplify normal anatomical variations or radiographic noise (17). In contrast, the higher specificity demonstrated by PSP plate imaging indicated a greater ability to correctly identify sound interproximal surfaces. This finding suggested that the wider exposure latitude and smoother image appearance characteristic of PSP systems may reduce overinterpretation of questionable radiolucencies. From a clinical standpoint, higher specificity may help minimize unnecessary preventive or restorative interventions, particularly in young adults where overtreatment can compromise tooth structure over time (18). The trade-off between sensitivity and specificity observed across the three techniques highlighted an ongoing diagnostic debate regarding whether early lesion detection or diagnostic certainty should be prioritized in routine practice (19).

Direct digital sensor imaging exhibited balanced but moderate sensitivity and specificity, consistent with its widespread use as a reliable diagnostic tool (20). While its immediate image acquisition and ease of integration into clinical workflows remain advantageous, the rigid sensor design and limited dynamic range may partially explain its reduced ability to detect early enamel lesions compared with enhanced imaging (21). Nonetheless, its overall performance supported its continued role as a standard diagnostic modality, particularly when combined with careful clinical judgment (22). Several strengths enhanced the credibility of the present findings. Standardized imaging protocols, examiner calibration, and blinded assessments minimized technical and interpretive bias. The focus on early enamel caries addressed a clinically meaningful stage of disease that is often underrepresented in diagnostic research. Additionally, the inclusion of multiple performance metrics allowed a comprehensive comparison of diagnostic utility rather than reliance on a single outcome measure (23).

Despite these strengths, certain limitations warranted consideration. The relatively small sample size limited the generalizability of the findings to broader populations and diverse clinical settings. The cross-sectional design precluded assessment of lesion progression over

time and limited conclusions regarding the predictive value of each technique. The reference standard relied on combined clinical and radiographic assessment rather than histological validation, which may have introduced some degree of diagnostic uncertainty. Furthermore, the study evaluated only three digital radiographic techniques, excluding emerging approaches such as artificial intelligence–assisted interpretation that may further influence diagnostic accuracy (24). Future investigations could expand on these findings by incorporating larger, multicenter samples and longitudinal follow-up to assess the clinical impact of early radiographic detection on treatment outcomes. The integration of advanced image analysis tools and decision-support systems may also offer opportunities to improve sensitivity while maintaining acceptable specificity. Comparative studies examining diagnostic performance alongside patient-centered outcomes and cost-effectiveness would further strengthen the evidence base for selecting optimal radiographic techniques (25).

CONCLUSION

Enhanced digital radiography improved the detection of early interproximal enamel caries, whereas PSP plate imaging reduced false-positive findings through higher specificity. Direct digital sensor imaging showed balanced diagnostic performance. Careful selection of radiographic techniques, aligned with preventive goals and clinical judgment, can enhance early caries diagnosis and support conservative management in young adult populations.

AUTHOR CONTRIBUTIONS

Author	**Contribution**
Alina Saghir	Substantial Contribution to study design, analysis, acquisition of Data Manuscript Writing Has given Final Approval of the version to be published
Ali Asmar Meer*	Substantial Contribution to study design, acquisition and interpretation of Data Critical Review and Manuscript Writing Has given Final Approval of the version to be published
Saher Ahmed	Substantial Contribution to acquisition and interpretation of Data Has given Final Approval of the version to be published
Fatima Chaudhary	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Usman Akram	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Zainab Hayat	Substantial Contribution to study design and Data Analysis Has given Final Approval of the version to be published

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