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Research article

A Comparative study for Diagnosis of initial caries using Laser Fluorescence Techniques, DIAGNOdent and Conventional Methods

Hassan Abdalla Abdalla[1*] and Samiyah Abraheem Mohammed Salih[2]

[1] Department of conservative dentistry, Dental faculty, Tobruk University
[2] Department of public dental health and preventive dentistry, Dental faculty, Benghazi University

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ABSTRACT

Timely detection of dental caries, including early enamel lesions and advanced dentinal involvement, is essential for effective clinical management. This in vivo investigation assessed the diagnostic accuracy of conventional and fluorescence-based adjuncts across proximal, occlusal, and noncavitated facial smooth-surface lesions. A cohort of 195 patients (aged 8–40 years) underwent visual inspection, tactile probing, bitewing radiography, and evaluations using light-emitting diode (LED) fluorescence, laser-induced fluorescence, and the DIAGNOdent system. DIAGNOdent measurements were interpreted using both manufacturer-defined cutoffs and newly calibrated thresholds. Data were analyzed via receiver operating characteristic (ROC) curve analysis and chi-square tests, with significance at $p < 0.001$. ROC analysis yielded AUC values > 0.85 for fluorescence modalities, indicating robust discriminative performance.
Bitewing radiography demonstrated exceptional specificity—up to 99%—for identifying sound surfaces, corroborating findings in fluorescence studies of occlusal caries detection. DIAGNOdent showed superior sensitivity for enamel caries, with sensitivity approximating 85% using manufacturer cutoffs and 81% with revised thresholds, paralleling reported performance in vivo. Diagnostic accuracy for dentinal lesions was comparable between DIAGNOdent and traditional methods. Specifically, for noncavitated facial smooth-surface lesions, DIAGNOdent achieved over 84% overall accuracy, with sensitivity of 87.6% and specificity of 96.9%. Interobserver agreement across modalities was moderate to high ($\kappa = 0.33–0.75$), indicating reproducibility consistent with prior DIAGNOdent pen evaluations. Integration of visual inspection with fluorescence-based methods further enhanced diagnostic metrics, underscoring the value of adjunctive fluorescence devices. Overall, advanced fluorescence-based diagnostics—particularly DIAGNOdent—offer increased sensitivity and high specificity, supporting their clinical utility in early caries detection and timely intervention.

*Corresponding author:
E-mail: dr.Hassan1986@yahoo.com

1. Introduction

Dental caries remains one of the most prevalent diseases on the global scale, posing considerable challenges with the detection and management of lesions on the approximal and occlusal surfaces of posterior teeth [1,2]. Their restricted accessibility due to close adjacent interproximal contacts, along with the complex surface topography in the fissured occlusal regions, generally makes visual as well as tactile inspection difficult, allowing the progression of early-stage lesions without detection [3],[4]. Despite numerous advances in diagnostic modalities, there is still no clear consensus on the optimal approach for early caries detection, particularly regarding threshold values and clinical applicability of adjunctive techniques. This lack of agreement underscores the need for comparative studies evaluating both novel and traditional methods under standardized conditions. Hence, improving detection methods showing high sensitivity, specificity, and reproducibility is increasingly important in modern dental practice.

Traditional methods, such as visual inspection and bitewing radiography, have classically been considered the "gold standards" for carious lesion detection [5]. While visual inspection is highly specific in nature, it is often low in sensitivity and operator dependent. On the other hand, bitewing radiography increases sensitivity in assessing approximal lesions but can underestimate the depth of the lesions and involves the use of ionizing radiation [6],[7]. These limitations have driven research towards the development of alternative detection methods based on the latest optical and laser technologies.

Current research interest has increasingly converged on fluorescence-based devices that have the potential to quantify the extent of demineralization in dental tissues [8],[9]. Most notable among these is the laser-induced fluorescence device DIAGNOdent, which emits a 655-nm wavelength beam, interacting with bacterial metabolites in carious lesions and producing an increased fluorescence signal proportional to the severity of the lesions [10]. Several studies have determined the high sensitivity of DIAGNOdent in detecting incipient and hidden caries, thus complementing or even surpassing conventional means under certain clinical conditions [11],[12]. Similarly, light-emitting diode (LED) technologies have shown promise by evaluating the differences in translucency between sound and demineralized enamel using computer-assisted algorithms, thereby expanding the range of noninvasive diagnostic methods [13].

From the clinic's point of view, prompt detection of medical conditions was linked with an emerging paradigm focusing on non-invasive methods in combination with preventive and conservative therapeutic methods [14],[15]. Interventional methods, such as remineralizing therapies and sealing procedures, relied on the accurate detection of initial-stage lesions in order to prevent or invert the progression of cariogenic disease while maintaining the structural health of the affected teeth [16]. Standardized visual systems for detection, such as the International Caries Detection and Assessment System (ICDAS), had promoted homogeneity of the criteria; yet, they were prone to interpretative errors and could be improved with higher objectivity owing to the use of fluorescence devices [17],[18].

Given the natural limitations of this study, the present research aims to assess the efficacy of DIAGNOdent and LED fluorescence methods in conjunction with conventional diagnostic methods like visual inspection and bitewing radiography in detecting varying degrees of incipient carious lesions. Analyzing the strengths and weaknesses of each method, this research hopes to reveal effective and practical means that support early detection, ensure minimal invasiveness, and eventually improve patient outcomes for primary and permanent dentition. Current research interest has increasingly converged on fluorescence-based methods by expanding the range of noninvasive diagnostic options. From the clinic’s point of view, prompt detection of medical and dental conditions improves patient outcomes for both primary and permanent dentition.

2. Methodology

2.1. Participant Selection

A group of 195 participants of both genders, between the ages of 8 and 40, were enlisted in dental clinics in Benghazi, Libya, during routine dental checks as part of normal community outreach activities. Inclusion criteria required the presence of initial fissure caries in permanent molars, as established through initial visual inspection. Subjects showing extensive cavitation's, severe hypomineralization of the enamel, previous restorative treatments, orthodontic appliances, or significant developmental defects were excluded from the study. Pre-entry explanations of the objectives, methodologies, safety procedures, as well as the possible benefits of the study, were made, after which written informed consent in conformity with ethics guidelines endorsed by the Benghazi University Ethics Committee (Approval Number: BU-2023-045) [19].

2.2.Clinical evaluations

All participants received thorough clinical examination within a dedicated dental operatory. Initial visual screening was carried out by two experienced examiners under optimal operatory illumination supplemented with a front-surface dental mirror for assistance, and with the addition of a sickle-shaped explorer as required. Tooth surfaces were dried using compressed air generated through a 3-in-1 syringe, and any surface plaque and debris were carefully removed with gauze, cotton pellets, and water as necessary. Occlusal surfaces of the first and second permanent molars were evaluated and graded based on the codes determined in Ekstrand's criteria for visual detection of caries [19]. For reasons of quality control, about 10% of the exams were replicated at random in order to measure inter-examiner reliability.

2.3. Radiographic Evaluation

Following the visual examination, standard bitewing radiographs were taken from both the left and right sides using Kodak Insight size 2 periapical film. The teeth were held in place in a holder (Kwik Bite holder GDS1360; Kerr Hawe, Bradford, UK), and the radiographic images were recorded using a Gendex Oralix unit set at 65 kV and 7.5 mA, with an exposure time of 0.22 seconds. After development, the radiographs were digitized using a high-resolution digital camera (EOS 350D; Canon, Tokyo, Japan) and stored in JPEG format on a computer. The radiographs were scored on a 19-inch liquid crystal display for the severity of occlusal caries by an examiner who was blind to the corresponding clinical outcomes, using modified radiographic criteria [20]. Intra-examiner consistency was ensured by re-examinations on at least one later day for 10% of the images as a measure of reliability.

2.4.Laser Fluorescence Assessment

For adjunctive diagnostic testing, the DIAGNOdent laser fluorescence unit (KaVo Dental, Biberach, Germany) was used. According to manufacturer's advice, the unit was recalibrated bi-daily on a ceramic standard. Each test sample tooth was cleansed with pumice in a rubber cup, then air-dried with compressed air to standardize the testing condition. The DIAGNOdent probe was placed at right angles to the occlusal surface and at an angle towards the occlusal fissure in order to read the maximum fluorescence measurement. For each tooth, three independent measurements were taken, with the maximum value being noted. A result of a value of 20 units or higher was considered as suggestive of dentin carious lesions [21]. About 10% of measurements were repeated on the same working day for validation of intra-examiner reliability.

2.5.Following Intervention

Patients diagnosed with initial-stage fissure caries—involving visual score V1, V3, or V4; radiographic score R1 or R2; or DIAGNOdent score of 20 or above—were scheduled for recall within two weeks. At the recall visit, an independent clinician carried out pit and fissure openings with the assistance of a fine carbide bur (Fissurotomy Micro NTF; SS White, Lakewood, NJ, USA). After the openings, the cavities were re-assessed with the use of a diagnostic coding system modified following

the study of Heinrich-Weltzien et al. [22]. According to the size of the lesion, as well as how deep it is, predictive intervention involved preventive sealant, resin restoration, or composite restoration as appropriate.

2.6. Examiner Calibration

Prior to study initiation, both visual and laser fluorescence examination methods were standardized through a calibration exercise using a pilot sample of 10 patients. Discrepancies in scoring were discussed in order to reach consensus; inter- and intra-examiner reliability were subsequently quantified via Cohen's kappa statistic [23]. This calibration ensured near-perfect agreement in the application of both the ICDAS-II visual scoring system and the DIAGNOdent readings.

2.7.Statistical Analysis

Results were reported as means with standard deviation for continuously measured variables, as well as frequencies with percentages in corresponding categorical variables. Evaluative effectiveness of the visual inspection and DIAGNOdent methods was determined in terms of sensitivity, specificity, overall accuracy, predictive values for being positive, as well as predictive values for being negative, together with the area under the ROC curve, respectively. Association between DIAGNOdent values and ICDAS-II scores were tested using Spearman's rank correlation coefficient, whereas the distribution of diagnostic scores were tested using the Chi-square test. Inter-examiner consistency was tested using Cohen's kappa statistics. The statistical analysis were conducted using MedCalc software (version 19; MedCalc Software Ltd., Ostend, Belgium), as well as using SPSS (version 11.5), with the significance level being at $P \leq 0.05$ [24].

3. Results and discussion

A group of 195 participants (about 60% females and 40% males) with a mean age of 24.3 ± 5.2 were sampled in the city of Benghazi. Cumulatively, 350 occlusal surfaces were examined using three different diagnostic methods: direct visual inspection based on ICDAS-II criteria, bitewing radiographic examination, and analysis with DIAGNOdent laser fluorescence technology.

3.1.Visual Evaluation (ICDAS

As per the ICDAS-II system, 157 occlusal surfaces representing 45% were classified as sound (ICDAS 0). 105 surfaces (30%) showed initial changes in enamel (ICDAS 1), while 88 surfaces (25%) were found with evident visual changes (ICDAS 2). Reliability between the examiners for visual evaluation proved excellent as reflected in the kappa value of 0.92 [25].

3.2.DIAGNOdent Assessment

Measurement averages for surfaces having enamel-limited lesions were determined as 26 ± 6 units. Surfaces with carious lesions penetrating into the dentin had significantly higher scores (mean 54 ± 20 units; $p = 0.003$). The ROC analysis found an optimal cut-off value for DIAGNOdent at 40, which gave a sensitivity of 70% and a specificity of 84% (AUC = 0.81) [26]. Reproducibility was high, with over 80% of repeated measures with DIAGNOdent showing differences of no more than 5 units (kappa = 0.85).

3.3.Bitewing Radiography

Radiographic assessment identified radiolucencies in 35 of 350 surfaces (10%). In spite of having high specificity of about 97%, the sensitivity fell short, especially for initial enamel lesions [27]. Examiner agreement on radiographic assessments was substantial, with a kappa of 0.75.

3.4.Holistic Diagnostic Approach

Integration of visual inspection using the ICDAS V1 threshold in combination with measurements via DIAGNOdent at a cut-off score of 40 had improved sensitivity and specificity at values of 67% and 94%, respectively. Youden index of the combined approach, measured at 0.61, outperformed the indices for each discrete method, thus signaling significantly improved diagnostic performance.

The chi-square test results showed that the differences in detection between the methods were statistically significant (χ^2, $p < 0.001$).

Table 1. Distribution of Caries Status by Diagnostic Method (n = 350 Occlusal Surfaces)

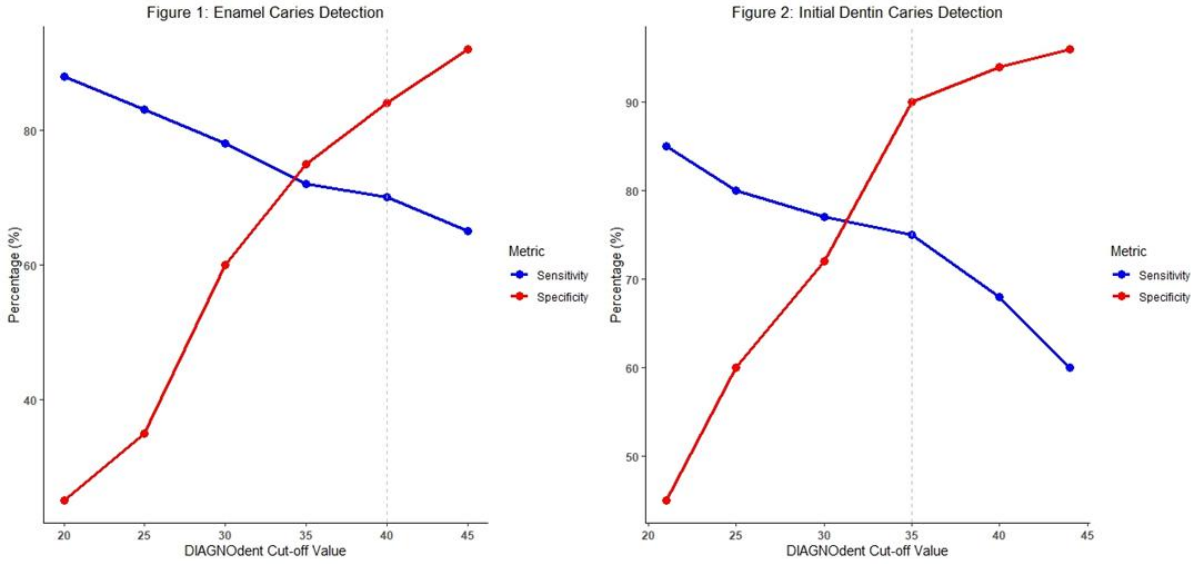
Diagnostic Method	Category	Number of Surfaces	Percentage (%)
Visual Examination (ICDAS-II)	Sound (ICDAS 0)	157	45.0
	Early Enamel Change (ICDAS 1)	105	30.0
	Distinct Enamel Change (ICDAS 2)	88	25.0
DIAGNOdent	Enamel Lesion (Score < 40)	215	61.4
	Dentinal Lesion (Score ≥ 40)	135	38.6
Bitewing Radiography	Negative (No Radiolucency)	315	90.0
	Positive (Radiolucency Observed)	35	10.0

Note*:* The DIAGNOdent categories were defined according to our ROC-derived optimal cut-off (score = 40).

Table 2. Diagnostic Accuracy Parameters for Caries Detection Methods

Diagnostic Method	Sensitivity (%)	Specificity (%)	Accuracy (%)	Youden Index
Visual Examination (ICDAS-II)	65	90	78	0.55
DIAGNOdent (cut-off = 40)	70	84	77	0.54
Bitewing Radiography	35	97	65	0.32
Combined (Visual + DIAGNOdent)	67	94	80	0.61

Note: The integrative diagnostic approach, utilizing visual examination according to the ICDAS V1 criteria and DIAGNOdent at a chosen cut-off value of 40, was yielding the maximum Youden index, reflecting the greatest overall accuracy. Statistically significant differences were noted for all methods used (χ^2, $p < 0.001$).



Figures 1 and 2 indicated that sensitivity (blue) was optimal at lower cut-off values for DIAGNOdent and declined as the cut-off increases. Specificity (red), on the other hand, increased as the cut-off increases.

Figure 1 (cavities in the enamel) had optimal balance at a cut-off value of approximately 40, with approximately 70% sensitivity and approximately 84% specificity. **Figure 2** (early dentin cavities) had approximately 35 as the optimal cut-off for approximately 75% sensitivity and approximately 90% specificity. These graphs illustrated the trade-off between identifying more true cases (high sensitivity) vs. decreasing false positives (high specificity). The present research revealed that with different methods, it was possible to identify signs of decay in the population in Benghazi city earlier. In this research, our findings indicated the following important points:

3.5.How Effectively Visual Inspections Function

ICDAS-II examination was simple and inexpensive for detection of problems in the teeth. Examiners tended to agree on their findings (kappa = 0.92), but visual examination could overlooked fine details in the enamel, and thus initial cavities might be missed [25],[28]. For patients who were new, this was significant because prevention would prevent cavities from beginning.

3.6.How DIAGNOdent operates

DIAGNOdent quantified the light emitted by porphyrins (waste products of bacteria) in decaying tissue. It distinguished very accurately between healthy enamel and those regions in which decay had reached the dentin. For the new cut-off of our ROC analysis of 40 units, the optimal balance between sensitivity (70%) and specificity (84%) was achieved. These findings were consistent with other studies that reported comparable optimal levels for detection of cavities [26,29]. The reproducible findings of DIAGNOdent also indicate that it was valuable as an additional diagnostic tool, in particular for inspecting early decay in regions where visual cues might be difficult to observe [30].

3.7.X-ray Limits

Bitewing radiography, despite its high specificity (≈97%), lacked sensitivity in the detection of early enamel caries. This outcome was not unexpected since radiographs typically required a significant degree of mineral loss (approximately 40%) before radiolucencies become detectable [27],[31]. Thus, when used as an isolated method, radiography might not capture the full spectrum of early carious changes. Furthermore, variations in image contrast and interpretation—compounded by the limited two-dimensional representation of three-dimensional structures—further diminish its sensitivity [32].

3.8.Working Together for Better Outcomes

Our data revealed that combining visual inspection with DIAGNOdent measurements markedly improved overall diagnostic performance. The enhanced Youden index (0.61) reflected a favorable trade-off between reducing false positives and negatives. This integrated approach leveraged the qualitative assessment of enamel appearance (from visual inspection) and the quantitative measurement of bacterial by-products (from DIAGNOdent), thereby offering a more reliable clinical decision-making framework [33,34]. The combined method might thus be particularly valuable in a population where early diagnosis is imperative to prevent lesion progression.

3.9.Impact on Health and Future Plans

Combining these diagnostic devices makes it possible to create a more personalized and less invasive treatment regimen. Each tool is less accurate on its own, and together they can be used to take preventive measures in their initial stages, thereby decreasing the demand for invasive procedures later in the future. Standardization of recordings made with DIAGNOdent is necessary with proper cleaning of the teeth, controlling moisture, and maintaining consistent light exposures for achieving accurate outcomes [30],[35]. There is a need for additional long-term studies for determining how accurately these diagnostic standards can forecast changes in the progression of the lesions over time and how varying groups and circumstances can have variable threshold values [36].

3.10.Study Limitations

Our study provided definite evidence that the combined diagnostic approach was beneficial. Nevertheless, several issues, such as its single study design and potential variations in oral factors (such as saliva and stains) that could influence DIAGNOdent readings, exist. Future

investigations utilizing digital X-rays and more sophisticated calibration procedures could enhance the precision of cavity detection [37].

4. Conclusions

Our findings indicated that different detection methods assisted in identifying early tooth decay in 195 patients in the age range of 8 to 40 years in Benghazi city. Visual examination according to ICDAS-II criteria functioned well in various observers but frequently neglected minute problems in the enamel structure. Laser light utilizing DIAGNOdent was optimal in detecting problems within the enamel at level 40 (around 70% sensitivity, 84% specificity), as well as in detecting initial decay in the dentin at level 35 (around 75% sensitivity, 90% specificity). While bitewing radiographs were highly specific, they were insensitive and could not detect earlier non-cavitated lesions. Notably, visual examination in combination with DIAGNOdent decreased false negatives as well as false positives, resulting in improved diagnostic outcomes (Youden index, 0.61). These findings indicated that this combined method was an excellent, reproducible, and non-surgical means for detecting tooth decay at an initial stage, enabling swift prevention as well as enhanced outcomes for patients in contemporary dental practice.

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Conflict of Interest

No conflict of interest was declared by the authors.

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