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Occlusal caries detection on 3D models obtained with an intraoral scanner. A validation study

P. Ntovas a, S. Michou b,c,*, AR Benetti b, A Bakhshandeh b, K Ekstrand b, C Rahiotis a, A Kakaboura a

a Operative Dentistry Department, School of Dentistry, National and Kapodistrian University of Athens, Greece
b Department of Odontology, Faculty of Health and Medical Sciences, University of Copenhagen, Denmark
c 3Shape TRIOS A/S, Copenhagen, Denmark

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ABSTRACT

Objectives: To evaluate the diagnostic performance of visual caries assessment on 3D dental models obtained using an intraoral scanner and to compare it with the performance of the clinical visual inspection.

Methods: Fifty-three permanent posterior teeth scheduled for extraction were randomly selected and included in this study. One to three independent examination sites on the occlusal surface of each tooth were clinically inspected using International Caries Detection and Assessment System (ICDAS) criteria. Afterwards, the examined teeth were scanned intraorally with a 3D intraoral scanner (TRIOS 4, 3Shape TRIOS A/S, Copenhagen, Denmark) using white and blue-violet light (415 nm wavelength) to capture the colour and fluorescence signal from the tissues. Six months after the clinical examination, the same examiner conducted the on-screen assessment of the obtained 3D digital dental models at the selected examination sites using modified ICDAS criteria. Both tooth colour and fluorescence texture with high resolution were assessed. Lastly, an independent examiner conducted the histological examination of all teeth after extraction. Using histology as the reference test, Sensitivity (SE), Specificity (SP), Accuracy (ACC), area under the Receiver Operating Characteristic (ROC) curve, and Spearman’s correlation coefficient were calculated for the clinical and on-screen ICDAS assessments.

Results: The ACC values of the evaluated methods varied between 0.59-0.79 for initial caries lesions and 0.77-0.99 for moderate-extensive caries lesions. Apart from SE values corresponding to caries in the inner half of enamel, no significant difference was observed between clinical visual inspection and on-screen assessment. In addition, no difference was found in the assessment of 3D models with tooth colour alone or supplemented with fluorescence for all the evaluated diagnostic measures.

Conclusions: On-screen visual assessment of 3D digital dental models with tooth colour or fluorescence showed a similar diagnostic performance to the clinical visual inspection when detecting and classifying occlusal caries lesions on permanent teeth.

Clinical significance: 3D intraoral scanning can aid the detection and classification of occlusal caries as part of patient screening and can potentially be used in remote caries assessment for clinical and research purposes.

1. Introduction

Visual examination remains the primary and most efficient method employed for occlusal caries detection [1]. However, this technique presents limitations due to the examiner’s subjective assessment and the relatively low reproducibility [2]. In addition, the detection of occlusal caries is impaired by various factors, including dental plaque, non-carious lesions (e.g., developmental defects), and obstacles during the examination process (e.g., insufficient light, presence of saliva) [2,3]. Thus, diagnosing and managing occlusal dental caries is still a challenge for general practitioners. Additionally, the inability to conduct blind examination on the subjects and the grading inconsistencies make visual examination fall short in large-scale epidemiological oral surveys, particularly considering expenses related to travel and working hours [1,4].

Dental photographs obtained with intraoral or extraoral cameras...
using white light or other light sources such as blue and near-infrared have been proposed for caries detection and monitoring, as well as remote assessment purposes [5]. Going one step further from the two-dimensional (2D) cameras, the three-dimensional (3D) intraoral scanner (IOS) has recently been introduced as a tool to support caries detection utilizing different optical caries detection methods [6–9]. Fluorescence using blue light excitation is one of the most promising technologies for detecting the earliest stages of enamel demineralization on occlusal and smooth surfaces. Fluorescence has recently been employed on a 3D intraoral scanner (TRIOS 4, 3Shape TRIOS A/S, Denmark) to aid caries detection and monitoring, presenting good results in vitro and in vivo [6,7,9]. Additionally, the near-infrared reflectance and transillumination methods have recently been implemented in commercial and prototype intraoral scanners for potential application both in proximal and occlusal caries detection showing good diagnostic performance [2,3,10]. Despite the widespread use of intraoral scanners in daily dental practice in developed countries, their application for diagnostic purposes such as caries detection and monitoring is still limited. This is partially due to the limited literature assessing their diagnostic performance [2,3,6,7,9,10].

Some of the limitations observed for the direct clinical visual examination or the use of digital photographs for caries assessment could be overcome by using intraoral scanner systems for detection and monitoring of caries lesions and other oral diseases [2,3,7–11]. More specifically, the imaging acquisition angle, which can significantly affect the size of the lesion depicted in photographs, is not expected to influence the assessment on 3D models. Therefore, the intraoral scanners can potentially enable the acquisition of reproducible images at different points in time for caries monitoring while eliminating the problems associated with the acquisition angle on 2D images. Additionally, proper lighting and magnification of the examined area that usually affect the visual clinical examination are not expected to affect the assessment on 3D models, as long as the intraoral scanner manufacturers’ instructions are followed during scanning. Furthermore, the obtained 3D models can be shared and assessed remotely by multiple dental experts, allowing properblinding of examiners in epidemiological surveys while at the same time reducing travel-related time and costs. Lastly, the optical caries detection methods (e.g., fluorescence and NIR reflection) implemented in modern intraoral scanners (TRIOS 4, 3Shape TRIOS A/S and iTero Element 5D, Align Technologies) and corresponding automated scoring systems (e.g., Caries indication provided by TRIOS Patient Monitoring software, 3Shape TRIOS A/S, Denmark) can potentially contribute towards more reliable and objective caries assessment compared to direct clinical visual examination [6,7,9].

Thus, this study aims to evaluate the diagnostic performance of on-screen visual caries assessment on 3D dental models obtained using an intraoral scanner and to compare it with the performance of the clinical visual inspection. The null hypothesis of the present study was that there is no difference in diagnostic performance between conventional clinical visual caries detection and on-screen caries detection on 3D digital models.

2. Materials and methods

The Standard Reporting of Caries Detection and Diagnostic Studies (STARCARDDS) was followed as closely as possible to report this article’s methods and results [12].

2.1. Study design

This was a cross-sectional in vivo study with in vitro validation. First, visual examination of teeth for caries detection and 3D intraoral scanning (3Shape TRIOS 4 A/S, Denmark) were conducted, and subsequently, the teeth were extracted. The 3D models of the teeth were examined on a digital monitor after tooth extraction. Finally, the histological assessment was performed as the reference test.

2.2. Study sample

Prior to the study’s onset, the estimated required sample size was defined based on the expected diagnostic performance for visual assessment employing ICDAS criteria, as derived by a previous study [7] and using the formula described by Buderer et al. [13]. More specifically, the following parameters were employed: Sensitivity (SE) at 0.93, Specificity (SP) at 0.88, absolute error at 0.1, confidence interval at 95%, and prevalence at 60%. Based on the above, a minimum of 101 examination sites on permanent molars and premolars should be included in the study.

Teeth scheduled for extraction due to therapeutic reasons at the Department of Oral Surgery and Periodontology of the School of Dentistry, National and Kapodistrian University of Athens were included in the study. Only adult participants ranging from 18 to 60 years old were included. The sample distribution according to tooth type was the following: 15 premolars (12 mandibular and 3 maxillary), and 43 molars (18 mandibular, 25 maxillary). Thus, 58 posterior teeth without calculus on their occlusal surfaces nor restorations, severe developmental defects or visible extensive caries on other surfaces than the occlusal were used.

The workflow of the study is presented in Fig. 1.

2.3. Clinical visual examination (ICDAS)

The clinical examiner (P.N.) was calibrated according to the recommendations from the ICDAS Committee [14,15]. Firstly, the examiner was trained to use these criteria on an educational software (ICDAS training software), and further training was accomplished with a second examiner (C.R.) trained and validated for using ICDAS criteria [14,15]. Initially, the two examiners scored 10 teeth independently and then discussed the scores presenting disagreement until they could reach an agreement. One week later, ten more teeth were scored. Again, the two examiners conducted the assessment independently and came to an almost perfect agreement (weighted kappa = 0.92).

Clinical oral examination of the patients was conducted prior to tooth extraction. Firstly, the plaque was removed from the occlusal surfaces of the examined teeth using prophylaxis brushes on a low-speed handpiece (Kavo Intra 20k, Italy). Afterwards, the clinical examiner (P.N.) defined one to three examination sites on the occlusal surface of each tooth (Fig. 1,i). Finally, the same examiner examined all the assigned sites clinically using the visual ICDAS criteria as presented in Table 1. The teeth were assessed visually under proper illumination of a dental lamp before and after air-drying.

2.4. 3D intraoral scanning

At the same appointment, following the visual examination and before tooth extraction, intraoral scanning was performed with a 3D intraoral scanner (TRIOS 4, 3Shape TRIOS A/S, Denmark) aided by commercial software (TRIOS vers. 1.18.2.11 and Dental Desktop vers.1.6.8.1, 3Shape TRIOS A/S, Denmark). The manufacturer’s recommendations were followed throughout the scanning. The dental lamp was switched off during intraoral scanning, and the teeth were air-dried thoroughly.

All teeth were first scanned with the intraoral scanner using the standard white light to obtain a 3D model with tooth colour texture (Fig. 1, ii), and thereafter with light at 415 nm to obtain fluorescence signal from the hard dental tissues. This fluorescence signal was applied to the previously created 3D model (Fig. 1,ii). The intraoral scanning procedure was considered adequate when the software obtained sufficient tooth colour and fluorescence information on the examined tooth by using a specific algorithm developed by the manufacturer and visualized as a blue overlay on the 3D model (TRIOS software, 3Shape TRIOS A/S, Denmark).
2.5. On-screen assessment on 3D dental models

Six months after the clinical examination, the 3D models of the teeth were examined under standardized light conditions by the clinical examiner (P.N.) on a laptop computer with a 15-inch monitor (VPCF1, Sony Vaio) and a custom-designed software (not commercially available software, 3Shape A/S, Denmark) (Fig. 1 ii). This software visualized the post-processed 3D models with high resolution as they appear on the commercial software (TRIOS vers. 1.18.4.0 or higher, 3Shape Dental Desktop, 3Shape). For the on-screen assessment of the 3D models (i.e., with tooth colour and fluorescence), modified ICDAS criteria described by Ferreira-Zandona et al. were used (Table 1) [16]. Firstly, only the 3D models with tooth colour texture were assessed, and afterwards, the models with the fluorescence texture. The same examination procedure was repeated two months later under the same conditions to evaluate the intra-examiner reliability.

2.6. Reference test - histology

An independent examiner (S.M.) conducted the histological assessment as the reference standard. This examiner was blinded to both the clinical and on-screen scores given by the clinical examiner (P.N). The histological analysis was conducted using multiple buccolingual cuts (obtained using Accutom, Struers A/S, Denmark with diamond disc thickness ~0.4 mm, Buehler, Illinois) on each tooth and consecutive manual grinding [8,11]. The absolute depth of the caries lesion and its corresponding enamel or dentin thickness was registered for each examination site using a stereomicroscope (SteREO discovery V8; Zeiss, Germany) and the accompanying software (DeltaPix InSight V 5.2.6, DeltaPix, Denmark; precision 0.01 mm) without staining (Fig. 1 iii).

Six different histological scores (E0, E1, E2, D1, D2, D3), as presented in Table 1, were assigned to each examination site according to the result from the fraction between the caries lesion’s depth and the total enamel or dentin thickness. The depth of the lesion extending into enamel was divided by the total enamel thickness; likewise, the depth of the lesion extending into dentin was divided by the total dentin thickness.

An independent score was assigned to each examination site from each method: direct clinical visual examination, on-screen assessment on 3D dental models, and histological assessment.
Table 1
Criteria used for histological assessment and corresponding scores used for clinical visual examination (ICDAS) and on-screen assessments.

<table>
<thead>
<tr>
<th>HISTOLOGY</th>
<th>Lesion Depth</th>
<th>HISTOLOGY Score</th>
<th>CLINICAL VISUAL ICDAS Score</th>
<th>ON-SCREEN Tooth colour 3D Model</th>
<th>ON-SCREEN Fluorescence 3D Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOUND</td>
<td>E0</td>
<td>0: Sound tooth surface with no visible evidence of caries, when viewed after cleaning and 5 seconds of air-drying</td>
<td>0: Sound tooth surface</td>
<td>0: Sound tooth surface</td>
<td></td>
</tr>
<tr>
<td>ENAMEL</td>
<td>E1 Inner half of enamel</td>
<td>1: First visual change in enamel, seen after 5 seconds of air-drying</td>
<td>1: First visual change in enamel</td>
<td>1: Slight fluorescence change</td>
<td></td>
</tr>
<tr>
<td></td>
<td>E2 Inner half of enamel, including the DEJ</td>
<td>2: Distinct visual change in enamel visible when both wet and dry, with no evidence of surface breakdown or underlying dentin shadowing</td>
<td>2: Distinct visual change in enamel</td>
<td>2: Distinct fluorescence change</td>
<td></td>
</tr>
<tr>
<td>DENTIN</td>
<td>D1 Outer third of dentin</td>
<td>3: White or brown spot lesion with localized enamel breakdown, without visible dentin exposure</td>
<td>3: Localized enamel breakdown due to caries with no visible dentin</td>
<td>3: Visible enamel breakdown with a distinct fluorescence change</td>
<td></td>
</tr>
<tr>
<td></td>
<td>D2 Middle third of dentin</td>
<td>4: Non-cavitated surface with an underlying dentin shadow, which obviously originated on the surface being evaluated</td>
<td>4: Surface with underlying dark shadow from dentin with or without enamel breakdown</td>
<td>4: Poorly delineated distinct fluorescence change with or without enamel breakdown</td>
<td></td>
</tr>
<tr>
<td></td>
<td>D3 Inner third of dentin</td>
<td>5: Visually distinct cavity in opaque or discoloured enamel and exposed dentin (less than half of the surface)</td>
<td>5: Distinct cavity with visible dentin (less than half of the surface)</td>
<td>5: Cavitation visible with distinct fluorescence change (less than half of the surface)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>6: Extensive and visually distinct cavity with exposed dentin (more than half of the surface)</td>
<td>6: Extensive distinct cavity with visible dentin (more than half of the surface)</td>
<td>6: Extensive cavitation visible with distinct fluorescence change (more than half of the surface)</td>
<td></td>
</tr>
</tbody>
</table>

![Fig. 2. Receiver operating characteristic (ROC) curves for clinical and on-screen visual assessments at different histological levels.](image-url)
2.7. Outcome variables

The outcome variables in this study consisted of a correlation ($r_s$) between the histological scores and the scores from the index tests, as well as diagnostic accuracy metrics for the index tests at the different histological cut-offs. Additionally, the intra-examiner reliability for the on-screen visual assessment was also calculated.

2.8. Data analysis

The $r_s$ was used to evaluate the correlation between the clinical visual and on-screen assessments and the histological scores. ROC curves (Fig. 2) and contingency tables were made using histology as the reference standard (Appendix tables A1, A2, A3). The diagnostic performance of the index tests (clinical and on-screen assessments) was expressed using the area under the ROC curve (Az), SE, SP, and ACC at the different histological cut-offs. The SE and SP were the true positive and true negative rates respectively when considering the histological scores as reference. The ACC was given as the sum of true positive and true negative scores obtained from the clinical and on-screen assessments divided by the total number of scores. The weighted Cohen’s kappa coefficient ($\kappa$) with quadratic weights was calculated for the intra-examiner reliability for the on-screen visual assessment.

Nonparametric test (McNemar’s) was used to compare the SE and SP values of the index tests. The Az from the investigated methods were compared pairwise using DeLong’s algorithm [17]. IBM SPSS Statistics (Version 26, IBM Corporation, IL, USA) was used to calculate Spearman’s correlation coefficient ($r_s$), the Az and the $\kappa$, create the cross-tabulations, and conduct the nonparametric statistical analyses. The Az comparisons were performed using MedCalc statistical software (Version 19.6.4, MedCalc Software Ltd, Belgium). Other calculations, i.e., SE, SP, ACC, were done in Excel (Microsoft Office 2016) based on the cross-tabulations exported from SPSS.

The confidence level was defined as 95% for all statistical tests.

3. Results

Fifty-eight teeth met the inclusion criteria and were evaluated but five teeth were destroyed during the preparation for histological analysis. Finally, 53 teeth with 118 examination sites were histologically assessed and included in the present study. The distribution of examination sites into the different histological levels was: 17 sound sites, 25 E1, 54 E2, 8 D1, 9 D2 and 5 D3 sites. Due to insufficient colour or fluorescence data on some 3D models, the final number of examination sites included for the on-screen assessments was 112. Cross tabulations are provided in the Appendix (Tables A1, A2, A3).

The intra-examiner reliability expressed by quadratic weighted kappa was 0.86 (Std. Error 0.04) for the assessments on tooth-colour models, and 0.80 (Std. Error 0.06) for the model assessments combining colour and fluorescence information.

The $r_s$ as well as the descriptive results (Az, SE, SP, ACC) at each histological level are presented in Table 2. In addition, ROC curves for each evaluated method are shown in Fig. 2.

Both assessment methods showed moderate correlation with the histology ($r_s$), ranging from 0.49 to 0.54. At the pre-defined histological levels, both methods (clinical visual examination and on-screen visual assessment) showed no significant difference in Az (Az $> 0.65$, $p < 0.05$). Regarding initial caries lesion stages (E1-E2 histological scores), the diagnostic accuracy (ACC) ranged from sufficient (0.59) to good (0.79). For the moderate-extensive caries lesions, diagnostic accuracy ranged from good (0.77) to excellent (0.99).

There was no significant difference in the results (SE, SP, Az) from the on-screen visual assessment conducted on the 3D models with tooth colour or when tooth colour and fluorescence texture were combined ($p > 0.05$). When comparing the clinical visual examination results to those from the on-screen assessments, the only significant difference was observed for SE at the E2 histological level, in which the clinical visual examination resulted in a significantly higher value ($p < 0.05$). No other significant difference was observed among the different methods. SE was higher for initial caries lesions in enamel (E1) than deeper enamel lesions (E2).

4. Discussion

The present study showed that the 3D digital dental models deriving from introral scanning could be used for occlusal caries detection and classification. Furthermore, there was no overall significant difference in the diagnostic performance of direct clinical visual examination and on-screen visual examination of digital 3D models. Thus, digital 3D models displaying tooth colour and/or fluorescence can be used to detect and, to some extent, classify dental caries, even if there is no opportunity for a direct clinical examination.

Moving one step further from the visual assessment of 3D dental models, automated caries detection and classification on 3D models using specific software has previously been investigated [4,7]. Such automated system was not included in the current paper. However, previous investigations on the same study sample [13] or other samples [4,7] have shown that the mentioned automated system results in

Table 2

The Az, SE, SP, ACC and the correlation with histology r_s results for all methods assessed. The standard error is provided in parentheses. The standard errors for SE and SP are adjusted for clustered data. The different letters next to Az, SE, and SP values represent statistically significant differences in the same row (A > B , $p < 0.05$).

<table>
<thead>
<tr>
<th>Histology</th>
<th>Measure (Std. Error)</th>
<th>Clinical visual</th>
<th>Method</th>
<th>On-screen - Tooth Colour</th>
<th>On-screen - Fluorescence &amp; Tooth Colour</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Az</td>
<td>0.54 (0.07)</td>
<td>0.49 (0.07)</td>
<td></td>
<td>0.50 (0.07)</td>
<td></td>
</tr>
<tr>
<td>SE</td>
<td>0.76 (0.06)*</td>
<td>0.77 (0.05)*</td>
<td></td>
<td>0.76 (0.05)*</td>
<td></td>
</tr>
<tr>
<td>SP</td>
<td>0.82 (0.03)*</td>
<td>0.75 (0.06)*</td>
<td></td>
<td>0.74 (0.05)*</td>
<td></td>
</tr>
<tr>
<td>ACC</td>
<td>0.59 (0.04)*</td>
<td>0.71 (0.01)*</td>
<td></td>
<td>0.65 (0.02)*</td>
<td></td>
</tr>
<tr>
<td>E2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Az</td>
<td>0.71 (0.05)*</td>
<td>0.66 (0.05)*</td>
<td></td>
<td>0.68 (0.05)*</td>
<td></td>
</tr>
<tr>
<td>SE</td>
<td>0.72 (0.05)*</td>
<td>0.57 (0.06)*</td>
<td></td>
<td>0.61 (0.06)*</td>
<td></td>
</tr>
<tr>
<td>SP</td>
<td>0.60 (0.03)*</td>
<td>0.63 (0.03)*</td>
<td></td>
<td>0.60 (0.03)*</td>
<td></td>
</tr>
<tr>
<td>ACC</td>
<td>0.68</td>
<td>0.59</td>
<td></td>
<td>0.61</td>
<td></td>
</tr>
<tr>
<td>D2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Az</td>
<td>0.90 (0.04)*</td>
<td>0.90 (0.05)*</td>
<td></td>
<td>0.91 (0.04)*</td>
<td></td>
</tr>
<tr>
<td>SE</td>
<td>0.93 (0.07)*</td>
<td>0.85 (0.09)*</td>
<td></td>
<td>0.85 (0.09)*</td>
<td></td>
</tr>
<tr>
<td>SP</td>
<td>0.75 (0.02)*</td>
<td>0.83 (0.04)*</td>
<td></td>
<td>0.80 (0.02)*</td>
<td></td>
</tr>
<tr>
<td>ACC</td>
<td>0.77</td>
<td>0.83</td>
<td></td>
<td>0.80</td>
<td></td>
</tr>
<tr>
<td>D3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Az</td>
<td>1.00 (0.01)*</td>
<td>0.99 (0.01)*</td>
<td></td>
<td>0.99 (0.01)*</td>
<td></td>
</tr>
<tr>
<td>SE</td>
<td>1.00 (0.001)*</td>
<td>1.00 (0.001)*</td>
<td></td>
<td>1.00 (0.001)*</td>
<td></td>
</tr>
<tr>
<td>SP</td>
<td>0.99 (0.001)*</td>
<td>0.96 (0.002)*</td>
<td></td>
<td>0.96 (0.002)*</td>
<td></td>
</tr>
<tr>
<td>ACC</td>
<td>0.99</td>
<td>0.96</td>
<td></td>
<td>0.96</td>
<td></td>
</tr>
</tbody>
</table>
similar diagnostic performance to the conventional caries detection methods (visual, radiographic) of occlusal lesions using ICDAS criteria. The latter could further assist the clinical examination by potentially reducing the examination time and increasing the objectivity and reproducibility of caries detection and monitoring on 3D models [5].

In the current study, the ACC of both evaluated methods was higher for more extensive caries lesions than initial lesions. The lower SE of the on-screen examination at the E2 level can be explained by the fact that the ICDAS 2 criterion could not be applied on-screen like it is done in the clinical examination, where it is possible to observe the lesion wet and then dry [4,5]. Additionally, the current study results showed no significant differences in the diagnostic performance when assessing models only with the tooth colour texture or supplemented with fluorescence information. This indicates that the high resolution and the reproduced tooth colour were sufficient for on-screen caries assessment, and fluorescence did not add important information. However, this result does not agree with the literature [16,18,19], where improved SE is usually achieved when the fluorescence method is employed for initial caries detection due to the fluorescence method’s advantages in detecting early enamel demineralization and the presence of bacteria metabolites. This can potentially be explained by the differences among the systems employing fluorescence method, such as differences in the wavelength used for fluorescence excitation, the fluorescence signal adjustment, and the image processing before the visualization on the screen. On the other hand, an increased number of false-positive indications is also often reported for the fluorescence method due to image artefacts, surface defects (e.g., developmental), and the presence of plaque [5,7,16], which was not observed in the current study. We speculate that this study’s results might have been different if the sample either included a more significant number of initial lesions (E1) or if the assessment of the fluorescence texture was conducted independently rather than in conjunction with the tooth colour assessment. These aspects can be considered for future work.

The findings of this study support the use of intraoral scanning for patient screening for caries, for example, as part of different remote patient screening modalities, especially for disadvantaged remote living populations [20]. Digital technology could help perform well-documented diagnoses and treatment planning by external dental experts and update the knowledge of the local dental staff in remote areas, as it can also serve as a distance learning tool [20]. Other possibilities include assisting consultation among various specialties, and remote emergency care screening [20,21]. Literature also shows that besides the assessment of caries lesions [4,5,7,9], these 3D models can be used to assess gingivitis and tooth wear [10,11]. By combining the 3D dental models and images with clinical and digital radiographic assessments, the data can easily be shared among dental practitioners and assist in multidisciplinary diagnosis and treatment planning without the need for the patient’s physical presence [22]. For this purpose, it is essential to deliver the imaging devices to the areas where the patients are located and to share the images with healthcare practitioners. Although the intraoral scanners for 3D dental model acquisition are relatively expensive and not yet implemented in the majority of dental clinics, particularly in developing and rural areas, it is expected that these devices will become more affordable and available worldwide. Additionally, such intraoral scanners can be carried and operated by non-dental personnel, e.g., nurses visiting patients in remote areas or elderly homes.

Some limitations are identified in the current study. First, the teeth included in this study were scheduled for extraction due to different therapeutic reasons, which led to a sample not representative of the general population. The sample was mainly formed by third molars, while a smaller number of teeth were extracted for orthodontic reasons or due to periodontal disease. In contrast, the teeth assessed and monitored in daily clinical practice usually include premolars, and first and second molars, with initial to moderate caries lesions. Second, only primary occlusal caries lesions were assessed and thus, other types of caries lesions shall be assessed, such as proximal caries [9], caries in the esthetic area and caries around restorations. Third, lesions in the outer third of dentin (D1 based on the histology), were not presented separately in the results of this study, as D1 has no direct corresponding ICDAS score within the visual examination to allow reliable discrimination between lesions located only in enamel or in the outer third of dentin [17]. Finally, our study evaluated only ICDAS scores without mentioning the caries activity, which influences caries lesion management.

5. Conclusions

Within the limitations of the current study, we conclude that on-screen visual inspection of caries lesions on 3D dental models obtained using an intraoral scanner can be used to aid the detection and classification of occlusal caries with an accuracy equivalent to that of the clinical visual inspection. Further studies are required to assess the clinical reliability of the method and the diagnostic accuracy when assessing other types of caries lesions and tooth surfaces.

CRediT authorship contribution statement

P. Ntovas: Conceptualization, Methodology, Investigation, Visualization, Writing – original draft. S. Michou: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Funding acquisition, Visualization, Writing – review & editing. AR Benetti: Conceptualization, Methodology, Resources, Writing – review & editing, Supervision, Funding acquisition. A Bakhshandeh: Conceptualization, Methodology, Resources, Writing – review & editing, Supervision, Funding acquisition. K Ekstrand: Conceptualization, Methodology, Resources, Writing – review & editing, Supervision, Funding acquisition. C Rahiotis: Conceptualization, Methodology, Resources, Writing – review & editing, Supervision, Project administration. A Kakaboura: Conceptualization, Methodology, Resources, Writing – review & editing, Supervision, Project administration.

Declaration of Competing Interest

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Ethics

This study received ethical approval from the Research Ethics Committee of the School of Dentistry (National and Kapodistrian University of Athens) (protocol number 423/08.07.2019). The study was conducted according to the declaration of Helsinki and the General Data Protection Regulation (GDPR). All study participants gave informed consent.
Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.jdent.2023.104457.

References


