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Article

In vitro Evaluation of Magnification and LED Illumination for Detection of Occlusal Caries in Primary and Permanent Molars Using ICDAS Criteria

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Abstract: Background: Early detection of occlusal caries in children is challenging for the dentists, because of the morphology of pit and fissures. Aim: The aim of the present study was to investigate the use of low-powered magnification (×2.5) and its association with LED headlight illumination for occlusal caries detection in primary and permanent molars using International Caries Detection and Assessment System (ICDAS) criteria.Methods: The occlusal surfaces of 36 extracted teeth (n=18 primary molars, n=18 permanent molars) were examined using ICDAS criteria with unaided visual examination, low-powered magnification and low-powered magnification plus LED headlight illumination. Three examiners evaluated one occlusal site per tooth twice independently with one week interval, using all methods. The teeth (n = 36) were sectioned and examined under light microscopy using Downer's histological criteria as the gold standard. Results: The weighted kappa values for inter- and intraexaminer reproducibility for the ICDAS examinations were almost perfect (Kappa values 0.72–0.96) in all three examination methods. The correlation with histology and overall AUC performance (0.96–0.98) of low-powered magnification plus LED headlight illumination was statistically significant in permanent molars. In primary molars, both low-powered magnification (0.82–0.90) and low-powered magnification plus LED headlight illumination (0.87–0.93) showed statistically significant correlation with histology and good to excellent AUC performance than unaided examination. Conclusion: Visual aids have the potential to improve the performance of early caries detection and clinical diagnostics in children.

Keywords: ICDAS, dental caries, magnification, headlight, primary molars, permanent molars, visual aids

1. Introduction

Caries incidence in industrialized nations has decreased over the last few decades, with the greatest reductions occurring on the smooth and approximal surfaces [1]. The main objective of contemporary dentistry is to diagnose dental caries at the earliest possible stage to allow the clinician the opportunity to implement effective management strategies [2]. Whilst one of the most readily accessible tooth surfaces, detection of occlusal caries has always been challenging for the dental clinician [3]. Early detection of carious lesions in children is especially important because of the thinner enamel in primary molars and immature structure of the pit and fissure system in permanent molars. Thus, it is important to develop sensitive, specific and reproducible diagnostic tools for precise caries management [4]. Despite many new novel technologies, visual examination still is the most commonly used method for detecting caries. Since unaided visual examination has been shown to have low sensitivity and low reproducibility, a standardized scoring system, International Caries Detection and Assessment System (ICDAS), has been developed for clinical practice, epidemiology studies, research and education [5–7]. The ICDAS is an evidence-based system that standardizes data collection thus enabling proper comparison between studies [2,7] (Table 1).

Table 1. International Caries Detection and Assessment System (ICDAS) Criteria.

ICDAS Code	Clinical criteria description
0	Sound tooth surface: no evidence of caries after prolonged air drying (5 s)
1	First visual change in enamel: opacity or discoloration (white or brown) is visible at the entrance to the pit or fissure after prolonged air drying, which is not or hardly seen on a wet surface
2	Distinct visual change in enamel: opacity or discoloration distinctly visible at the entrance to the pit and fissure when wet, lesion must still be visible when dry
3	Localized enamel breakdown due to caries with no visible dentin or underlying shadow: opacity or discoloration wider than the natural fissure/fossa when wet and after prolonged air drying
4	Underlying dark shadow from dentin ± localized enamel breakdown
5	Distinct cavity with visible dentin: visual evidence of demineralization and dentin exposed
6	Extensive distinct cavity with visible dentin and more than half of the surface involved

To improve precision of clinical procedures and for ergonomic reasons, dental loupes and the more recently introduced LED headlight illumination mounted on dental loupes, have become popular among dentists [8]. With its small operating field, pediatric dentistry would particularly benefit from dental loupes and other visual aids. However evidence-based studies supporting their effectiveness in children are lacking.

Therefore, the aim of the present study was to investigate the use of low-powered magnification (×2.5) and its association with LED headlight illumination for occlusal caries detection in primary and permanent molars using ICDAS criteria.ICDAS

2. Materials and Methods

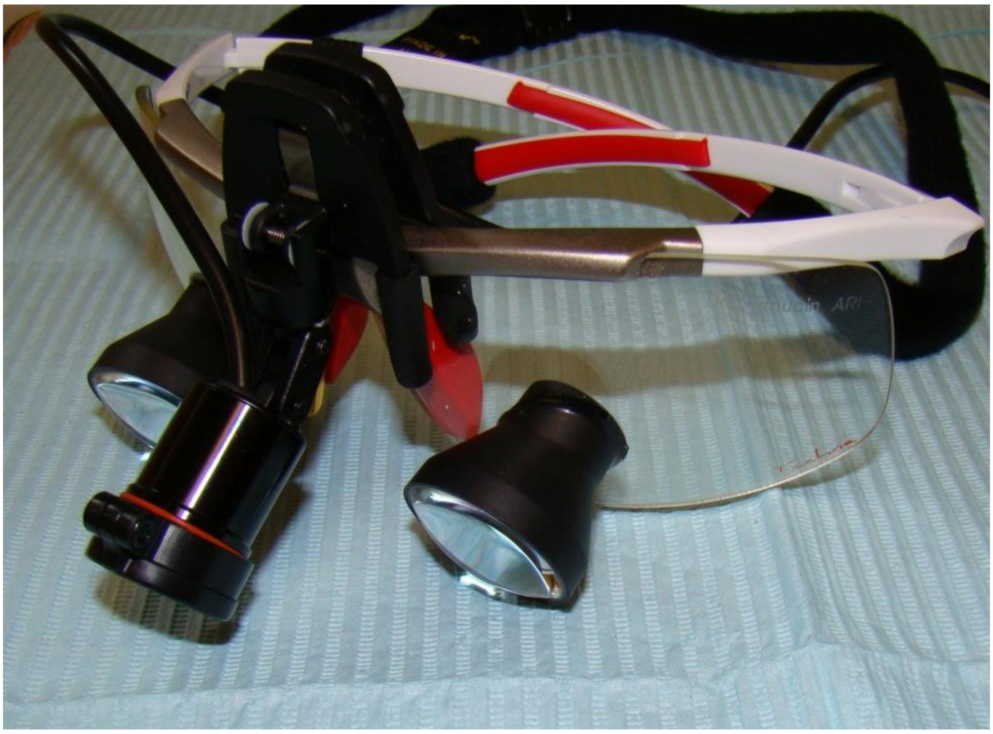
Prior to undertaking the study, ethical approval was granted by Western University Research Ethics Board for Health Sciences Research (File number 101093). Recently extracted second primary molars (n=18) and first permanent molars (n=18) were selected for this *in vitro* study. Extracted teeth were kept in 10% neutral buffered formalin immediately following extraction. In order to assess the accuracy of clinical examination, only teeth with non-cavitated and cavitated in enamel level (ICDAS Codes 1 to 3) were selected; teeth with extensive cavitation, occlusal restorations, occlusal fissure sealants and hypoplastic pits were excluded from this study. Prior to examinations, each tooth surface was cleaned with pumice and water slurry to remove any debris and rinsed thoroughly in sterile water. The teeth were mounted in pairs (second primary molar and first permanent molar) into impression putty (VP Mix Putty, Henry Schein Inc, US) in order to mimic intraoral anatomical position for mixed dentition.

Before the visual examinations, three examiners (two pediatric dentists and one prosthodontist) took the e-learning training available at ICDAS webpage (http://www.icdas.org/courses/english/index.html) for the detection of occlusal carious lesions. Examiners were calibrated by a training exercise followed by discussion to consensus of any uncertainties. The details of each score were discussed and a series of images of the occlusal surface and corresponding histological appearance were shown to demonstrate that subtle changes at the entrance to the fissure could correspond to marked histological changes.

In order to determine intra- and interexaminer reproducibility, 15 teeth (seven primary molars and eight permanent molars), which were not included in the present study examined by three examiners on two separate occasions with two weeks interval.

Once intra- and interexaminer agreement achieved (Kappa > 0.75), examination of 36 teeth (18 primary 2nd molars, 18 permanent 1st molar) for the study was carried out. All examinations were conducted under standard conditions in dental surgery, with conventional dental light (A-dec, Oregon, USA) and 3:1 syringe. The teeth were positioned 40 cm to examiners’ eyes and kept wet during the examinations unless when dried for ICDAS examination. A general dentist who had experience working with ICDAS codes before, selected one occlusal site per tooth. Examiners were guided by black and white photographs printed on draft-quality paper containing a dot on the test site to allow the precise assessment of the same area. The specific site was hidden by a dot to avoid biasing during examinations by the photographic images. The three examiners, who had no experience in using dental loupes and LED headlight before, examined teeth independently. In order to eliminate the chance of memorizing previous scores, each examination technique was repeated blinded to previous scores after a waiting period of one week. The examinations were first carried out with unaided visual examination. One week later, examinations were repeated using custom made (2.5 × magnification) dental loupes (Univet Optical Technologies, Italy) and a week after that, (2.5 × magnification) dental loupes plus LED headlight illumination (Univet Lite LED Optical Technologies, Italy) was used for examinations (Figure 1).

Figure 1. 2.5 × magnification dental loupe with LED headlight.

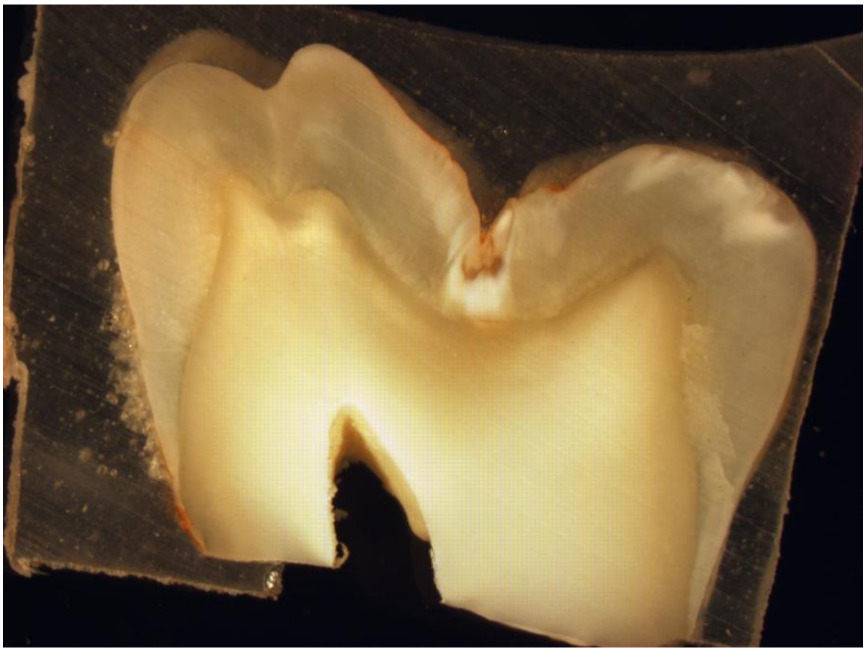


After all examinations were completed, the roots of the teeth were resected just apical to the cementum-enamel junction prior to histological examination (Figure 2). A marker was placed on the mesial cervical area of each tooth and nail varnish was applied to this mesial groove to aid identification of tooth surfaces and therefore orientation after sectioning.

To obtain the histological sections, each tooth was immersed in orthodontic resin (Caulk Orthodontic Resin, Dentsply, USA) and allowed to set into blocks (36 individual blocks) of 1 cm per side. Each mounted block was then serially sectioned in a longitudinal boccolingual direction with a water-cooled diamond disc on a thin sectioning machine (Gillings-Hamco, NY, USA). The examination site was identified using photographs and around this location 1 to 4 sections were cut approximately 350 µm thick. The sections were separated from the block and numbered for examination. After sectioning the grooves and artifacts left by the diamond disc were polished with a fine-grained paper coated with 600, 1200 and 2400 grade aluminum oxide (Al2O3). In total 7–10 sections were produced per crown and 1–4 sections were available to view for each investigation site.

Histological sections were examined under a Nikon SMZ-1500 stereomicroscope (Nikon Instruments, Inc, Melville, NY) and digital images were captured with incident light at x 16 magnification.

Figure 2. Histological section of a permanent molar.



All histological sections for each tooth were assessed by two trained examiners (N.A and T.A) who were blinded to each other according to five-point scale Downer histological classification system (Table 2) [9]. Caries extent was based upon colour and structural changes in enamel and dentine, with emphasis being placed on differentiating carious changes from protective changes of the pulp-dentine complex, such as tubular sclerosis and reactionary dentine formation. A histological score was given to each section and the deepest score section was taken as the definitive for further analysis. Where there was disagreement, two examiners reviewed the sections again and new examinations were performed until a consensus decision was reached.

Table 2. Criteria used in the histological examination (12).

Score	Criteria used in the Downer histological examination (12)
0	No enamel demineralisation or a narrow surface zone of opacity (edge phenomenon)
1	Enamel demineralisation limited to the outer 50% of the enamel layer
2	Demineralisation involving the inner 50% of the enamel, up to the enamel-dentine junction
3	Demineralisation involving the outer 50% of the dentine
4	Demineralisation involving the inner 50% of the dentine

3. Data Management and Statistical Evaluation

Both the ICDAS and histology scores were recorded on special sheets and transferred to an Excel table. The statistical analysis was performed using MedCalc v.9.0.1.1 statistical package (MedCalc Software, Mariakerke, Belgium nter- and intraexaminer reproducibility of ICDAS scores for primary and permanent molars were measured using kappa-Cohen statistical test. Kappa values above 0.75 denoted excellent agreement, while values between 0.40 and 0.75 indicated good agreement [10].

For each examiner, the relationship between the visual scoring systems and the histological scoring system was assessed using the Spearman rank correlation. Data obtained from these measurements were used to calculate sensitivity and specificity at the D1 diagnostic threshold as gold standard. At the D1 diagnostic threshold the sensitivity and specificity for each examiner was obtained using ICDAS cut-off 1–2. To correctly reflect the D1 diagnostic threshold all lesions including those with an ICDAS code 1 have been classed as caries. The use of a gold standard is a prerequisite in assessing the ROC (Receiver Operating Characteristic) curve [11]. This analysis involves a plot of pairs of sensitivity and '1-specificity' for a given cut-off value of a diagnostic test. Since this study is focusing on early detection of carious lesions, we select D1 level as diagnostic threshold. Using these sensitivity and specificity values, area under ROC curve (AUC) was carried out for each investigator and method. The performance of each method (AUC) was interpreted by using the following classification: 0.50–0.60 fail, 0.60–0.70 poor, 0.70–0.80 fair, 0.80–0.90 good, and 0.90–1.0 excellent [11]. The McNemar test was used to compare the sensitivity, specificity and AUC between examiners and examinations.

4. Results

A total of 36 teeth were examined with the three detection methods by three examiners and by histology. Table 3 and 4 shows intraexaminer reproducibility analysis for primary and permanent molars respectively. The degree of intraexaminer agreement for three examination methods was excellent (0.75–0.96). The weighted kappa values for interexaminer reproducibility with three different examination methods also showed good to excellent agreement (0.72–0.95) between examiners (Table 5 and 6).

Table 3. Intraexaminer reproducibility of ICDAS examinations (Weighted Kappa) for Primary molars.

	Unaided visual examination	Low powered magnification	Low powered magnification+LED
Examiner 1	0.85	0.78	0.88
Examiner 2	0.95	0.80	0.95
Examiner 3	0.77	0.94	0.82

Table 4. Intraexaminer reproducibility of ICDAS examinations (Weighted Kappa) for Permanent molars.

	Unaided visual examination	Low powered magnification	Low powered magnification+LED
Examiner 1	0.87	0.79	0.92
Examiner 2	0.96	0.81	0.95
Examiner 3	0.75	0.95	0.83

Table 5. Interexaminer reproducibility of ICDAS examinations (Weighted Kappa) for Primary molars.

	Unaided visual examination	Low-powered magnification	Low-powered magnification+LED
Examiner 1 *vs.* Examiner 2	0.94	0.78	0.81
Examiner 2 *vs.* Examiner 3	0.95	0.83	0.72
Examiner 3 *vs.* Examiner 1	0.89	0.75	0.72

Table 6. Interexaminer reproducibility of ICDAS examinations (Weighted Kappa) for Permanent molars.

	Unaided visual examination	Low-powered magnification	Low-powered magnification+LED
Examiner 1 *vs.* Examiner 2	0.95	0.77	0.80
Examiner 2 *vs.* Examiner 3	0.94	0.82	0.73
Examiner 3 *vs.* Examiner 1	0.91	0.76	0.74

Area under curve values (AUC), sensitivity and specificity of the examination methods based on D1 diagnostic threshold are presented in Table 7 and Table 8 respectively for primary and permanent molars. At the D1 diagnostic threshold, the sensitivity results for all examiners and examinations were between 0.57 and 1 for primary teeth and 0.84 and 1 for permanent teeth. Specificity values ranged 0.40 to 1 in primary teeth and 0.40 to 0.60 in permanent teeth. The overall AUC performance in primary molars was 0.65 to 0.70 for unaided examination and 0.82 to 0.93 when visual aids were used. AUC performance for permanent molars was between 0.66 to 0.71 for unaided examination and 0.80 to 0.98 for visual aids. In permanent molars AUC performance of low-powered magnification plus LED headlight illumination showed statistically significant higher values than other examinations. In primary molars, both low-powered magnification and low-powered magnification plus LED headlight illumination showed statistically significant higher AUC performance than unaided visual examination.

Table 7. Area under the ROC curve (Standard Error), sensitivity and specificity at D1 diagnostic threshold in primary teeth. AUC+Area under the curve; SE=standard error * Statistically significant difference (p<0.05)

Primary Molars	Unaided visual examination			Low powered magnification			Low powered magnification+LED		
D1 Diagnostic Threshold	Examiner 1	Examiner 2	Examiner 3	Examiner 1	Examiner 2	Examiner 3	Examiner 1	Examiner 2	Examiner 3
AUC (SE)	0.70 (0.14)	0.65 (0.13)	0.67 (0.13)	**0.82 (0.10)***	**0.86 (0.11)***	**0.90 (0.07)***	**0.93 (0.04)***	**0.87 (0.09)***	**0.92 (0.05)***
Sensitivity	0.62	0.57	0.50	0.75	0.87	0.87	1	0.87	1
Specificity	0.80	1	0.80	0.80	0.80	0.60	0.50	0.40	0.40

Table 8. Area under the ROC curve (Standard Error), sensitivity and specificity at D1 diagnostic threshold in permanent teeth. AUC+Area under the curve; SE=standard error * Statistically significant difference (p<0.05)

Permanent Molars	Unaided visual examination			Low powered magnification			Low powered magnification+LED		
D1 Diagnostic Threshold	Examiner 1	Examiner 2	Examiner 3	Examiner 1	Examiner 2	Examiner 3	Examiner 1	Examiner 2	Examiner 3
AUC (SE)	0.66 (0.15)	0.71 (0.14)	0.66 (0.15)	0.80 (0.09)	0.86 (0.07)	0.71 (0.14)	**0.96 (0.02)***	**0.98 (0.01)***	**0.97 (0.02)***
Sensitivity	0.84	0.92	0.84	0.92	1	0.92	1	1	1
Specificity	0.40	0.40	0.40	0.40	0.40	0.40	0.60	0.60	0.40

Spearman's correlation coefficients for examiners showing the relationship between examinations using Downer classification system are presented in Table 9. It is generally accepted that a correlation coefficient of 0.70 or above represents a strong relationship between two variables. The correlation between low-powered magnification plus LED headlight illumination and histology was statistically significant in permanent molars. In primary molars, statistically significant correlations with histology were found in examinations where low-powered magnification and low-powered magnification plus LED headlight illumination was used.

Table 9. Spearman's correlation coefficients for examiners showing the relationships between examinations using Downer classification systems. * Correlation significant at the 0.05 level.

	Examiner 1		Examiner 2		Examiner 3	
	Permanent Molars	Primary Molars	Permanent Molars	Primary Molars	Permanent Molars	Primary Molars
Unaided visual examination *vs*. Histology	0.38	0.37	0.39	0.36	0.38	0.37
Low powered magnification *vs*. Histology	0.51	**0.70***	0.62	**0.72***	0.41	**0.70***
Low powered magnification & LED *vs*. Histology	**0.78 ***	**0.78***	**0.83***	**0.73***	**0.81***	**0.77***

5. Discussion

Occlusal surfaces accounts for the majority of new carious lesions, effecting both primary and permanent dentition in children. Although occlusal surfaces are the most visited sites during clinical examination, complex occlusal anatomy and histopathology of the disease makes detection of early caries lesions difficult [12–15]. One of the purposes of the ICDAS system is to overcome this shortfall and describe the earliest visible changes on all tooth surfaces [12]. Clinical results of the ICDAS system provide an acceptable prediction of caries depth [16] and scientific data for reproducibility of ICDAS caries detection are promising. Rodrigues *et al*. [13], obtained kappa values of 0.61 for intraexaminer reproducibility and 0.51 for interexaminer reproducibility in permanent teeth. Jablonski-Momeni *et al*. [12], after a training session in an *in vitro* study, found unweighted kappa values ranging from 0.32 to 0.61 for interexaminer reproducibility and from 0.54 to 0.65 for intraexaminer reproducibility. In a study where ICDAS codes were used in both primary and permanent teeth [17], intra and interexaminer reproducibility were found to be excellent (weighted kappa values > 0.82). According to Ismail *et al*. [2], the ICDAS presents good to excellent reproducibility, (kappa coefficients ranged between 0.59 and 0.91) even when used by examiners who have no previous experience. In the present study, although examiners were new to ICDAS system, unaided visual examination showed excellent intraexaminer reproducibility (0.75–0.96). Despite having different clinical background (two pediatric dentists and one prosthodontist), the interexaminer reproducibility in the present study was also excellent for unaided visual examination (0.89–0.95). These results indicate that the use of a standard criterion for visual inspection tends to increase the intra- and interexaminer agreement and makes ICDAS system a highly reproducible diagnostic modality for occlusal caries diagnosis.

Even when using a detailed system, there might be a degree of subjective interpretation and discrepancies due to perhaps visual perception and lighting problems. This is why we assessed the impact of low-powered magnification and LED headlight illumination with ICDAS examinations. Surprisingly, very little scientific research with diverging results about the influence of visual aids on caries detection has been published to date. One study showed the use of low-powered magnification significantly improved the accuracy of examination [18] whereas a more recent article found the use of magnification caused a drop in reproducibility of the ICDAS scores [19]. None of the examiners in our study used visual aids before but our results showed good to excellent intra- and interexaminer reproducibility with low-powered magnification and LED headlight illumination. Based on our results, these popular visual aids can easily be used in daily clinical practice without affecting the reliability of the examinations.

In vitro studies usually establish the validity of a detection system by using a gold standard against which the sensitivity and specificity of the diagnostic method can be calculated. The moderate to strong relationship of ICDAS scores with histological extent demonstrates its potential to monitor lesions with time and benefit modern caries management methods [12]. Histological validation of caries and in particular occlusal caries is notoriously difficult as preparing thin sections entails tooth tissue loss and hemisecting a tooth through the lesion may not always pass through the deepest aspect of the lesion in question. These problems arise because of the three dimensional nature of the spread of caries dictated by the complex anatomy of the occlusal surface. A lesion may originate at one site on the surface of the tooth but spread obliquely and non-symmetrically beneath the tooth surface. To overcome this problem and to record the deepest aspect of the lesion, we examined 1–4 sections from each tooth depending on the severity of the lesion. The worst histological score, from these histological sections was recorded as reference section. Downer histology classification system [9] was used in this study to calculate sensitivity and specificity at the D1 diagnostic threshold for each examiner and examination methods. At the D1 diagnostic threshold, the sensitivity values ranged between 0.57 and 1 for primary teeth and 0.84 and 1 for permanent teeth. Specificity values ranged 0.40 to 1 in primary teeth and 0.40 to 0.60 in permanent teeth. These values differ with the previous studies where sensitivity scores ranged 0.69 to 0.92 and specificity scores ranged 0.79 to 0.82 at the D1 diagnostic threshold [12, 20]. A good explanation for this low performance might be the selection criteria of teeth in this study where the majority of those with caries had early carious lesions. AUC performance in previous studies using ICDAS at D1 threshold ranged from 0.67 to 0.86 [12, 13, 21]. In our study, the overall AUC performance for unaided examination in primary molars was poor, whereas good to excellent AUC performance was recorded when visual aids were used in primary molars. AUC performance in permanent molars was similar when unaided examination and low-powered magnification was used. However excellent AUC performance was observed in permanent molars when low-powered magnification plus LED headlight illumination was used. In this study the correlation between unaided visual examination and histology (0.36–0.39) was not as strong as previous studies where Spearman's correlation coefficient values ranged from 0.48 to 0.78 [12,19–21]. However, better correlation with histology was found when visual aids such as low-powered magnification and LED headlight illumination were used. To our best knowledge, this is the first study carried out using low-powered magnification plus LED headlight illumination on extracted primary and permanent teeth. Haak *et al*. [22], and Mitropoulos *et al*. [19], found no significant relationship between unaided examination and magnification in permanent teeth. Our study showed similar results when unaided examination (0.38–0.39) or low-powered magnification (0.41–0.62) was used in permanent molars. However, when low-powered magnification plus LED headlight illumination was used in permanent molars, strong correlation (0.70–0.72) and statistically significant difference with other examinations was found. In primary molars, low-powered magnification and low-powered magnification plus LED headlight illumination examinations showed strong correlation (0.73–0.83) with histology and statistically significant difference with unaided examination. According to our results visual aids had a remarkable positive impact on early caries detection in both primary and permanent molars. A good explanation for this impact might be; the increase in the depth of vision and the intensity/brightness of white light, which enhance the visibility of occlusal anatomy.

Within the limitations of this small sample size *in vitro* study it can be concluded that; the use of low-powered magnification and LED headlight illumination compliments ICDAS system in caries detection. Clinicians should keep in mind that visual aids have the potential to improve the performance of early caries detection and clinical diagnostics in children.

Conflict of Interest

The authors declare no conflict of interest.

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