Use of digitally optimized images of ICDAS caries codes by undergraduate dental students

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Objectives: In dentistry, images of teeth with sound and carious surfaces are often used as a tool for training purposes in the cariology curriculum. This study aimed to evaluate the diagnostic performance of the visual scoring system ICDAS (International Caries Detection and Assessment System) for detection of dental caries applied by undergraduate students when digitally optimized images of extracted teeth are used.

Material and method: Extracted teeth with ICDAS codes 0-6 were photographed ($Image_{conventional}$). Then, digitally optimized images were produced from the same investigation sites ($Image_{compound}$). Ten third-year dental students without previous experience in using ICDAS (group A) and ten fifth-year students experienced in the use of ICDAS (group B) participated in the study. All images were examined and a random selection of approximately 67% was reassessed after one week. Examiner reproducibility was calculated using weighted kappa values. Diagnostic performance (area under the ROC curve, AUC) was calculated at the D1 (enamel lesions) and D3 (dentine lesions) diagnostic threshold using ICDAS consensus scores of two experienced examiners (reference scores).

Results: Kappa values for intra- and inter-examiner reproducibility were moderate to almost perfect. No significant difference between the mean kappa values of the two groups was observed. In group B the AUC was significantly higher at the D1 diagnostic level when optimized digital images were examined.

Conclusion: The use of optimized digital images by students with ICDAS experience led to a significantly better performance in the detection of enamel lesions.

Keywords: diagnostics; caries detection; dental education; undergraduate students

1. Introduction

For a long time, caries was commonly detected and registered in accordance with the WHO standard, that is, lesions were only registered at the cavitation level. According to the WHO definition [1] dentine caries is registered if exposed dentine is visible or undermined enamel with softened enamel margins can be felt. Now, however, fewer and fewer carious lesions are being registered at the cavitation level due to improved preventive measures. Accordingly, the requirements placed on detection methods have increased in order to enable caries to be detected in the initial stage.

A suitable method for detecting enamel and dentine caries is the "International Caries Detection and Assessment System" (ICDAS). Introducing the ICDAS was intended to establish long-term a standardized method for adequate diagnosis of dental caries in dentists' offices, in epidemiological studies and in teaching [2]. In the long term, the use of ICDAS should enable studies to be better incorporated into overviews or meta-analyses and thus fulfill the requirements of evidence-based dentistry [3]. Studies already published show the ICDAS to have good to very good examiner reproducibility and a good diagnostic performance [4-8]. The ICDAS is also being used increasingly in clinical examinations [9-12].

The "Association for Dental Education in Europe (ADEE)" drafted a catalog of requirements for the European teaching curriculum and defined core competences of dentists graduating in Europe [13]. On the subject of "clinical information gathering", it says, "On graduation, a dentist must be competent at: ... Identifying the location, extent and degree of activity of dental caries, tooth wear and other structural or traumatic anomalies and the reason for their occurrence..." At present a "national competence-based dental learning objective catalog" ("Nationaler Kompetenzbasierter Lernzielkatalog Zahnmedizin, NKLZ") is being created based on regions. Here appropriate work packages also treat the subject of "hard tooth structure defects", which also includes adequate detection and diagnosis of dental caries.

Digital media are being used increasingly in dental teaching. Especially in caries detection, images of teeth are often used for training purposes. One advantage of using images is the possibility of enabling larger groups of students to engage in discussions using projected images. Hence the content and procedure of the teaching can be standardized. Using extracted teeth is now subject to specific regulations on the part of the ethics commissions, and what is more, there are not always enough extracted teeth available for each characteristic form of caries. If there is no intra-oral camera available, caries diagnosis exercises on patients can become rather cumbersome, depending on the size of the group.

The informative value of images viewed on a monitor or using a beamer essentially depends on the quality of the images. Since carious changes in a tooth are three-dimensional changes, information is inevitably lost when they are photographed and displayed in two dimensions. This problem can be minimized by a special photographic technique followed by digital image processing. This photographic technique (a thorough description of which is found in "Materials and Methods") and subsequent digital processing can achieve a sort of "depth of focus". Thus various occurrences of carious lesions can also be more precisely displayed in a photograph. Even wet and dried lesions, a special feature of assessment using the ICDAS method, can be presented with more nuances.

Using images with depth of focus can lead to more thorough training and thus to an improvement in teaching. The present in-vitro study focuses on the following questions:

1. How high is the examiner reproducibility of the ICDAS findings of experienced and less experienced students?
2. Does using digital images with "depth of focus" make a significant difference in the diagnostic performance of the ICDAS of experienced and less experienced students compared to conventional photographs?
3. Does differentiating between wet and dry tooth surfaces on digital images yield a significant difference in the diagnostic performance of the ICDAS?

2. Materials and Methods

2.1 Preparation of the teeth

Sixty extracted permanent teeth were available to the study. In conformance with the regulations effective at the time the study was planned, the patients were informed that their teeth would be used for scientific purposes before their teeth were extracted and their written consent obtained. After extraction, the teeth were first stored in a disinfectant solution (0.5% solution of chloramine T trihydrate), cleaned (scaler, polishing brush and paste) and then stored in water. All teeth were then numbered and adjudged by two examiners according to the ICDAS criteria [14] (consensus data as reference standard, Table 1). One examiner had already had many years of experience with the ICDAS method and attained high reproducibility, sensitivity and specificity scores with the method [6, 7, 15]. The intra-examiner kappa value for this examiner had been determined in previous examinations and was 0.93 (95% confidence interval 0.81-1.00). The second examiner had been thoroughly instructed in the system and completed theoretical and practical training before the examinations, although no separate kappa values were established.

On each tooth, either the occlusal surface or a lesion on approximal or smooth surfaces was incorporated in the examinations.

2.2 Producing the digital images and image processing

The teeth were fixed on an object slide with modeling clay. The object slides were blackened to avoid light reflections and achieve better contrast. They were clamped singly in an orthostat (from Leitz, Wetzlar) for the photographs. It was possible to move the object slides in all three dimensions by way of the precision adjustment on a lifting table (EK 14 75x50mm, from Märzhäuser GmbH, Wetzlar). A digital gauge was used to register the raising and lowering of the lifting table (i.e., movement along the z-axis).

The images were produced using a digital reflex camera (Olympus E 330) coupled to the orthostat with an adapter (Olympus OM Adapter MF-1). The ring light which was used was covered with a layer of cellulose to create diffused light and reduce troublesome light reflections on the surfaces of the teeth (Fig. 1). The camera was adapted to the lighting conditions by way of manual white balance with the aid of a white object slide.

Fig. 1 Digital reflex camera coupled to the orthostat for photography.

On each tooth, the highest point in the progression of the z-axis was marked with a black felt pen (HP). A green mark (MP) was placed between this point and the lowest point of the lesion or fissure (TP). These marks served as orientation points for focusing the camera (Fig. 2).

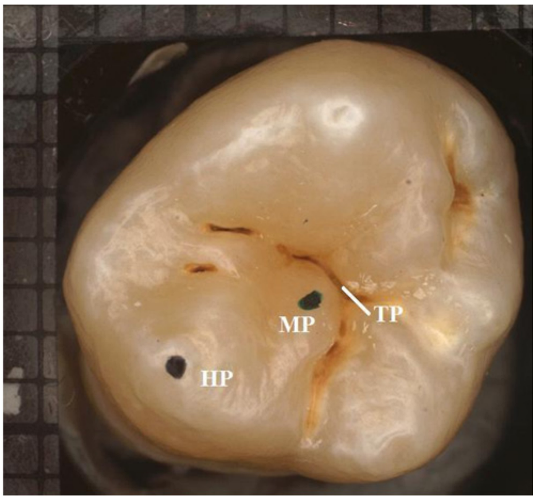

Fig. 2 Example of an occlusal surface with orientation points for focusing the camera.

From each tooth, a conventional photograph was made ($Image_{conventional}$) and a series of images to be put together later ($Image_{compound}$). Apart from the ICDAS codes 5 and 6 (cavitations), all photographs were taken in a dry ($Image_{dry}$) and wet ($Image_{wet}$) state. The drying was done for five seconds with a multifunction syringe. To wet the teeth, 10 µl of water was applied with a pipette and spread evenly.

A photograph was taken focused on the MP point for $Image_{conventional}$. Since the camera cannot record all levels of a tooth surface with the same sharp focus owing to the limited depth of focus, the following procedure was used: first several macro-photographs per tooth were taken, each with the focus set to varying heights. Starting from HP, the tooth with the object slide was brought up to the lens in 0.5-mm steps using the lifting table and photographed at each step. The number of images depended on the depth of the lesion and came out to between ten and fifteen images per tooth. The number of images was combined into one image ($Image_{compound}$) by a mathematician/computer scientist with special software (Helicon Focus, Globell B.V., Venlo, Netherlands). This process is referred to as "focus stacking" or "deep focus fusion". For all the images produced ($Image_{conventional}$ and $Image_{compound}$, both dry and wet), color contrast and brightness correction was performed with the Gimp (GNU Image Manipulation Program, www.gimp.org) image editing program in order to offset possible deviations. Sample images photographed under various conditions are shown in Fig. 3.

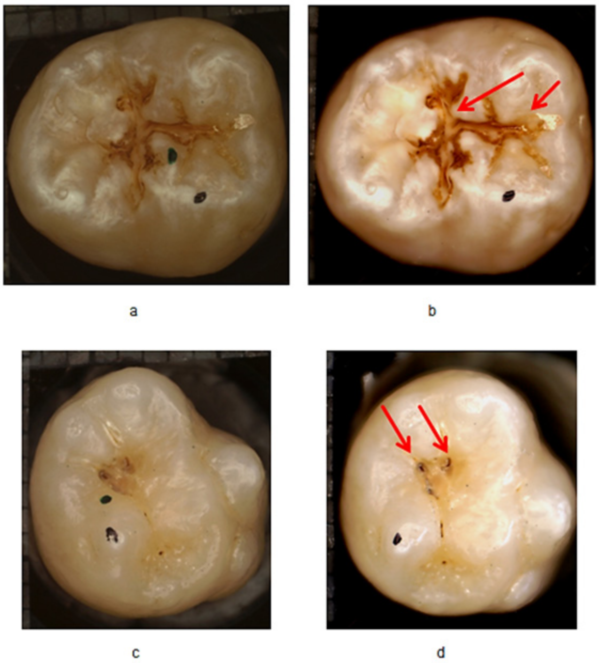

Fig. 3 a-d: Examples for ICDAS codes, photographed under different conditions. Each of the arrows points to the areas which exhibit a distinct depth of focus compared to the respective $Image_{conventional}$.

a) Code 1, $Image_{conventional/dry}$

b) Code 1, $Image_{compound/dry}$

c) Code 2, $Image_{conventional/dry}$

d) Code 2, $Image_{compound/dry}$

2.3 Examiners and recording the findings

The project was implemented for sixth and tenth semester dental students at the dental clinic of the Philipps University in Marburg in the summer semester of 2012 (Phantom-III course and Course II of conservative dentistry, respectively). For organizational reasons, ten participants per semester were recruited on a voluntary basis.

The ICDAS had already been introduced to the teaching program at the clinic. At the time of the study, the sixth semester students had already gained theoretical knowledge (according to a standardized procedure involving lectures, seminars and an e-learning program), and performed practical exercises on extracted teeth. The tenth semester students had been through the same training two years previously, that is, in their Phantom-III course [15]. In addition, they had applied the ICDAS to patients in their conservative dentistry I and II courses.

All the images were collected in random order in a file. Here attention was paid to ensuring that both the order of the various ICDAS codes as well as the various photographs ($Image_{conventional}$, $Image_{compound}$, $Image_{wet}$ and $Image_{dry}$) was random. The lesion to be assessed was marked on each image.

A second file contained approximately 67% of the images, also in random order. Both files and a findings sheet were made available to the students electronically. The images in the second file were to be diagnosed one week after the first run-through.

The students were told that they were supposed to diagnose the images according to the ICDAS classification as a means of improving the teaching of courses. They were told nothing about the objective of the study nor that the diagnosis of the images in the second file served to determine examiner reproducibility. This procedure was intended to exclude as far as possible any examiner "bias".

2.4 Statistical analysis

The scores were recorded on documentation sheets designed for this purpose and submitted to the office of the principal investigator. All the data were first transferred to an Excel file and then evaluated with the MedCalc® statistics program, version 12.4.0. The agreement of the examiners with the reference examiner (inter-examiner reproducibility) and the consistency of each examiner (intra-examiner reproducibility) were determined using Cohen's kappa. The weighted kappa coefficient (linear weighting) was determined for the ICDAS codes. The kappa values (κ) were evaluated according to the following classification: κ<0.00 poor agreement, κ=0.00-0.20 low, κ=0.21-0.40 adequate, κ=0.41-0.60 moderate, κ=0.61.0.80 substantial and κ>0.80 nearly perfect agreement [16].

The mean kappa values of both groups were tested for differences in mean values using the t-test. To determine the diagnostic performance of the examinations, the scores from the students were compared to a reference standard. In doing so, the consensus findings of the two experienced examiners ($ICDAS_{reference}$) were defined as the reference standard which was defined under the following conditions:

1. Caries at the D1 threshold ($ICDAS_{reference}$0 vs. $ICDAS_{reference}$1-6, i.e., enamel and dentine lesions)
2. Caries at the D3 threshold ($ICDAS_{reference}$0-2 vs. $ICDAS_{reference}$3-6, i.e., dentine caries).

The reference standard was used to compile receiver operating characteristic (ROC) curves and to calculate the area under the curve (AUC). The AUC is considered to a measure of the diagnostic performance and was evaluated as follows: 0.60-0.70=low, >0.70-0.80=adequate, >0.80-0.90=good and >0.90-1.00=excellent [17].

The findings of the A and B groups were pooled in each case to calculate the AUC. The AUCs were compared using a non-parametric test [18] to examine the differences in diagnostic performance for each student and between the groups. The significance level was set at α=0.05.

3. Results

A total of 214 photographs were taken which were then diagnosed by each student in the first round. To test reproducibility, 144 randomly selected images were examined a second time. The distribution of the ICDAS scores is summarized in Table 1.

Table 1 Distribution of the ICDAS codes and the corresponding images

ICDAS Code	n teeth	$Image_{conventional/dry}$	$Image_{compound/dry}$	$Image_{conventional/wet}$	$Image_{compound/wet}$
0 = sound	11	x	x	x	x
1 = first visible sign of non-cavitated lesion seen only when the tooth is dry	10	x	x	x	x
2 = visible non-cavitated lesion seen when wet and dry	10	x	x	x	x
3 = microcavitation in enamel	9	x	x	x	x
4 = non-cavitated lesion extending into dentine seen as an undermining shadow	7	x	x	x	x
5 = small cavitated lesion with visible dentine: less than 50% of surface	4	x	x	-	-
6 = large cavitated lesion with visible dentine: more than 50% of surface	9	x	x	-	-
N total teeth	60	60	60	47	47
N total images		214			

The kappa values for the agreement between two examinations were as follows: in Group A the intra-examiner reproducibility was κ=0.63-0.90 (average 0.76), in Group B the value was between 0.53 and 0.87 (average 0.71). There was no significant difference in the mean kappa values between experienced and less experienced students (p=0.231).

The reproducibility values of the students to the reference standard (inter-examiner reproducibility) were between 0.43 and 0.73 (averages A: 0.59, B: 0.60). The mean inter-examiner kappa values of the two groups did not significantly differ (p=0.969).

The diagnostic performance of the examinations was determined using the areas under the ROC curves (AUC). All values were consistent with a good to very good diagnostic performance: Group A: D1 threshold 0.91-0.93, D3 threshold 0.81-0.88; Group B: D1 threshold 0.92-0.96, D3 threshold 0.80-0.89. Significant differences were ascertained between the two groups at the D1 threshold between the AUC for $Image_{compound}$ (p value=0.004), $Image_{dry}$ ($p < 0.001$) and the combination $Image_{compound/dry}$ (p=0.003).

4. Discussion

This study examined the reproducibility and diagnostic performance of the ICDAS visual caries detection method when digital images are used. The results of examiner reproducibility showed satisfactory kappa values for experienced and less experienced students. Thus all values for intra-examiner reproducibility were located in the substantial to nearly perfect range of agreement. The reproducibility to reference examiners with several years of experience in cariology exhibited moderate to substantial kappa values. If we look at the mean kappa values, there was no significant difference between students in the sixth and tenth semester. In Group A (sixth semester) there was even a distinct tendency toward higher values (data not shown). This may possibly be related to the fact that the students had only recently received theoretical and practical instruction in ICDAS (during the current semester), while the tenth semester students had used the ICDAS with select patients on a supplementary basis, but an additional lecture unit on its theory was not on offer. Hence their theoretical knowledge had been gained two years previously. One possible explanation for these slightly lower kappa values could be the fact that the participants had not been explicitly advised to brush up on the theory before the study began. Added to this is the fact that the tenth semester students were already occupied with their preparations for the state examination and may have preferred to concentrate on other fields of learning.

A recent study showed that an additional theory lesson enhanced the reproducibility of students just starting to learn the ICDAS method [15]. However, the difference in the mean kappa values was not significant. The lack of a significant difference was explained by the low number of students participating. In the present study, ten students were available for each group. Hence a power analysis done post-hoc (G*Power, version 3.1.3) showed that a power of 0.80 (mean effect size, α=0.05) would only have been expected if there had been 48 students per group. Depending on the number of students available, it may be advisable to study these questions in the future using a multi-center approach. *Zandona et al.* [19] investigated the use of ICDAS in three different groups and obtained kappa values between 0.52 and 0.84. Here the differences in the agreement between students, graduates and teachers were not statistically significant. The authors concluded that previous clinical experience played no significant part in learning the ICDAS. In other studies [15], students in the sixth semester achieved intra- and inter-examiner kappa values which were lower on average than the results of our study. Current data [20] likewise show distinctly lower kappa values obtained by students on extracted teeth (intra- and inter-examiner kappa values: 0.17-0.80). However, there was no mention of whether these were simple or weighted kappa values. In our study, students took part in the examinations voluntarily. Hence the comparatively better kappa values could be related to more-highly motivated students being selected.

To determine the diagnostic performance of a method, histology is often used as gold standard. To avoid damaging the available teeth, our study defined the consensus scores as the gold standard or reference standard. This was done for the following reasons: collecting suitable extracted teeth is now quite difficult, one reason being that "informed consent" must be requested from patients. Therefore the teeth used here were not further fine-shaped with rotating instruments nor histologically prepared. Thus these teeth can be reused for subsequent studies. Because one of the reference examiners achieved very good reproducibility and high AUC values with the ICDAS [15], the decision to use reference standard as the "gold standard" was perfectly acceptable.

Zandona et al. [19] compared the performance of students and experienced examiners using the ICDAS on occlusal surfaces and could demonstrate no significant difference with regard to specificity and sensitivity between experienced and inexperienced examiners. In a study by *Diniz et al.* [21] students achieved AUC values of 0.80 before and 0.88 after using the ICDAS e-learning program. In this context, it is unclear whether this refers to the D1 or D3 threshold.

In our study, the use of optimized images by students with ICDAS experience led to significantly better performance in the detection of enamel lesions (D1 diagnostic threshold). This means that ICDAS codes 1 and 2 were better recognized by experienced students on the optimized images. On images made with dry surface, initial lesions were also assessed significantly better in the tenth semester. This suggests that the interpretation of the images by students improves after they have had some clinical experience. In this sense, the importance of ascertaining the diagnostic performance using images would have to be considered critically. It is obvious that the use of the ICDAS by students should be clinically tested in further studies.

5. Conclusion

Modern dentistry offers preventive and noninvasive methods of intervention, so that even small lesions can be treated with suitable procedures [22]. This in turn requires the use of differentiated methods of detection which can detect caries-related changes in hard tooth structures early on. The ICDAS is well established as a standardized system for detecting caries within the scope of a prevention-oriented teaching concept [23]. The requirements on the national competence-based learning objective catalog can also be fulfilled in the long term. What is more, the use of images facilitates export of the teaching method.

All students were able to use the ICDAS criteria irrespective of their clinical experience. The students participating in the study were able to achieve moderate to nearly perfect kappa values for intra- and inter-examiner reproducibility. Hence these results can serve as a motivation for other dental clinics to make use of the ICDAS method in their teaching. The use of optimized images enabled enamel lesions to be significantly better detected by students with experience in using the ICDAS method. Therefore producing such images is well worth the effort, especially for representing enamel lesions. These images are also well suited for use in postgraduate training.

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References

[1] WHO. Oral health surveys. Basic methods, ed 4. World Health Organization, Geneva 1997.
[2] Pitts N. "ICDAS"- an international system for caries detection and assessment being developed to facilitate caries epidemiology, research and appropriate clinical management. Community Dental Health 2004; 21:193-98.
[3] Richards D. Outcomes, what outcomes? Editorial. Evidence-Based Dentistry 2005; 6:1.
[4] Diniz MB, Rodrigues JA, Hug I, Cordeiro RCL, Lussi A. Reproducibility and accuracy of the ICDAS-II for occlusal caries detection. Community Dentistry and Oral Epidemiology 2009; 37:399-404.
[5] Ekstrand KR, Luna LE, Promisiero L, Cortes A, Cuevas S, Reyes JF, Torres CE, Martignon S. The Reliability and Accuracy of Two Methods for Proximal Caries Detection and Depth on Directly Visible Proximal Surfaces: An in vitro Study. Caries Research 2011; 45:93-9.
[6] Jablonski-Momeni A, Stachniss V, Ricketts DN, Heinzel-Gutenbrunner M, Pieper K. Reproducibility and accuracy of the ICDAS-II for detection of occlusal caries in vitro. Caries Research 2008; 42:79-87.
[7] Jablonski-Momeni A, Ricketts DNJ, Weber K, Ziomek O, Heinzel-Gutenbrunner M, Schipper H, Stoll R, Pieper K. Effect of different time intervals between examinations on the reproducibility of ICDAS-II for occlusal caries. Caries Research 2010; 44: 191-5.
[8] Shoaib L, Deery C, Ricketts DNJ, Nugent Z. Validity and Reproducibility of ICDAS II in Primary Teeth. Caries Research 2009; 43: 442-8.
[9] Braga MM, Ekstrand KR, Martignon S, Imparato JC, Ricketts DN, Mendes FM. Clinical performance of two visual scoring systems in detecting and assessing activity status of occlusal caries in primary teeth. Caries Research 2010; 44: 300-8.
[10] Ismail AI, Sohn W, Tellez M, Willem JM, Betz J, Lepkowski J. Risk indicators for dental caries using the International Caries Detection and Assessment System (ICDAS). Community Dentistry and Oral Epidemiology 2008; 36: 55-68.
[11] Pieper K, Weber K, Margraf-Stiksrud J, Heinzel-Gutenbrunner M, Stein S, Jablonski-Momeni A. Evaluation of a preventive program aiming at children with increased caries risk using ICDAS II criteria. Clinical Oral Investigations 2013; 17: 2049-55.
[12] Jablonski-Momeni A, Winter J, Petrakakis P, Schmidt-Schäfer S. Association of caries experience in 12-year-olds with independent variables in areas with low caries prevalence. International Journal of Paediatric Dentistry 2014; 24: 90-97.
[13] Cowpe J, Plasschaert A, Harzer W, Vinkka-Puhakka H, Walmsley AD. Profile and competences for the graduating European dentist – update 2009. European Journal of Dental Education 2010; 14:193-202.
[14] International Caries Detection and Assessment System (ICDAS) Coordinating Committee: Criteria Manual. Bogota, Colombia and Budapest, Hungary 2009 (www.icdas.org).
[15] Jablonski-Momeni A, Busche JF, Struwe C, Lange J, Heinzel-Gutenbrunner M, Frankenberger R, Pieper K. Use of the international caries detection and assessment system two-digit coding method by predoctoral dental students at Philipps University of Marburg, Germany. Journal Dental Education 2012: 76:1657-66.
[16] Landis JR, Koch GG. The measurement of observer agreement for categorical data. Biometrics 1977; 33:159-174.
[17] Tape TG. Interpreting Diagnostic Tests. University of Nebraska Medical Center. http://gim.unmc.edu/dxtests/.
[18] Hanley JA, McNeil BJ. A method of comparing the areas under receiver operating characteristic curves derived from the same cases. Radiology 1983; 148: 839-43.
[19] Zandona AGF, Al-Shiha S, Eggertsson H, Eckert G. Student Versus Faculty Performance Using a New Visual Criteria for the Detection of Caries on Occlusal Surfaces: An In Vitro Examination with Histological Validation. Operative Dentistry 2009; 34: 598-604.
[20] Foley JI. Dental students consistency in applying the ICDAS system within paediatric dentistry. European Archives of Paediatric Dentistry 2012; 13: 319-22.
[21] Diniz MB, Lima LM, Santos-Pinto L, Eckert GJ, Zandoná AG, de Cássia Loiola Cordeiro R. Influence of the ICDAS e-learning program for occlusal caries detection on dental students. Journal of Dental Education 2010; 74: 862-8.

[22] Jablonski-Momeni A, Heinzel-Gutenbrunner M: Efficacy of the "Self-assembling peptide P11-4" in the formation of a remineralization scaffold on artificially induced enamel lesions on smooth surfaces. Journal of Orofacial Orthopedics 2014; 75: 175-189.
[23] Pitts N. Preventive and minimal intervention dentistry in the undergraduate curriculum. Journal of Dentistry 2011; 39 (Suppl 2):S41-8.