Original Research
Cariology

Tactile perception of roughness to assess activity in artificial initial caries lesions with a novel force-controlled probe

Stefania MARTIGNON[a]
Gina Alejandra CASTIBLANCO-RUBIO[a]
Mariana Minabel BRAGA[b]
Andrea CORTES[a]
Margarita USUGA-VACCA[a]
Juan Sebastian LARA[a]
Fausto Medeiros MENDES[b]
Viviana AVILA[a]

[a]Universidad El Bosque, UNICA – Caries Research Unit, Research Department, Bogotá, Colombia.

[b]Universidade de São Paulo – USP, School of Dentistry, Department of Orthodontics and Pediatric Dentistry, São Paulo, SP, Brazil.

Declaration of Interests: The authors certify that they have no commercial or associative interest that represents a conflict of interest in connection with the manuscript.

Corresponding Author:
Stefania Martignon
E-mail: martignonstefania@unbosque.edu.co

https://doi.org/10.1590/1807-3107bor-2022.vol36.0134

Submitted: January 27, 2022
Accepted for publication: July 4, 2022
Last revision: July 12, 2022

Abstract: Roughness-tactile perception is part of activity assessment in initial-caries-lesions. Hypothesizing that a probe's design influences this examiner's assessment, four probes were designed. The aims of this study were to select the probe with highest inter-/intra-examiners' roughness-assessment agreement and to determine its diagnostic accuracy on artificial initial-caries lesions. A pilot study was conducted with trained dentists to select one controlled-pressure probe design (n = 4) by assessing roughness on known-roughness metal plaques with 5-point Likert scale. Diagnostic accuracy of roughness assessment was conducted with the selected controlled-pressure probe and the WHO-probe on sound and artificial initial-caries-lesion (n = 20) human enamel blocks. Intra-class correlation coefficients (ICCs) and quadratic weighted-Kappa scores were used to assess examiners' reproducibility and Multilevel Poisson models to determine diagnostic accuracy between both probes controlling for confounding variables. The probe design with the highest inter/intra-examiner's agreement (ICC = 0.96) was selected for subsequent analyses. Unadjusted sensitivity, specificity and accuracy values were for the controlled-pressure and the WHO probes: 71.1%,90.6%,81.2%, and 67.4%,84.6%,75.8%, respectively ($p > 0.05$). Examiner remained the most important factor influencing diagnostic accuracy. While this study did not show significantly higher diagnostic accuracy of the designed controlled-pressure vs. the WHO-probe when used by trained dentists, all over roughness-assessment accuracy and reproducibility were high.

Keywords: Dental caries, Dental enamel, Dental instruments, Tactile sensation, Diagnosis.

Introduction

Accurately assessing initial-caries-lesion activity leads to more appropriate caries-care planning/ control,[1-9] but it implies difficult clinical-parameter integration.[7-13] Active initial-caries-lesion ongoing mineral loss results in a rough-surface texture, which may result in tooth-structure loss/cavities.[2,11,14,15] Conversely, a smooth texture relates to arrested lesions/sound surfaces.[2,11,14]

Initial-caries-lesion roughness-tactile perception has *in-vivo* indicated activity[16] -more reliably than colour[17] -assessed with a ball-ended/WHO probe recommended by ICDAS (International Caries Detection and Assessment System) ICCSM™ (International Caries Classification and Management System) and CCI (CariesCare International).[7,8,18] Roughness-tactile perception assessment during the clinical examination of initial caries lesions (ICDAS 1 and 2, histologically located in enamel up to the outer-dentine third) is useful to determine whether the lesions are active (likely going through mineral loss) or conversely inactive.[10-13] The combination of visual and tactile parameters are the most frequently studied parameters as is stated by Nyvad and ICDAS/ICCMS criteria[15]. Moreover, a recent study has demonstrated the enamel texture (roughness) is the lesion feature that may better predict the caries lesions' progression.[19] Although it is a useful criterion for caries activity lesions status definition, it is a strongly subjective parameter.[20] One reason for such subjectivity is the pressure the examiner may exert when probing the surface. A manner to control the probe-exerted force used has been to include a pressure-stopper on probes in Periodontology.[21-22] In this sense, we designed four ball-ended probes (Marthe®, Bucaramanga Colombia), under the rationale that the examiner's exerted pressure, the handle's diameter/weight, the tip-arm length, and the rough/smooth tip, influence an examiner's roughness-tactile perception. These four caries-activity roughness-tactile perception probes were tested in this study, aiming at: 1-Selecting the probe with highest inter-/intra-examiners' roughness-assessment agreement; 2-Determining its diagnostic accuracy on artificial initial-caries lesions.

Methodology

Four ball-ended probes (Marthe®, Bucaramanga-Colombia), were designed taking into account different characteristics regarding the the handle's diameter (thick/thin) and weight (heavy/light), the tip-arm length and angle(long/short; 90°/120°), and the tip's roughness (rough/smooth). Probes' characteristics can be seen in table 1A. Additionally, probes had a stopper to control the examiner's applied pressure.

Ethics

This study is covered by the Ethics' Committee Approval at Universidad El Bosque (PCI 2013-421).

Study design

Pilot for the selection of the probe's design

A pilot study to select the controlled-pressure probe with the highest inter-/intra-examiners' agreement was conducted on standardized known-roughness metal plaques (Master-Visual-Tactual Set-GAR Electroforming, Danbury, USA). Plaques' roughness was: 0.10 µm (minimum-roughness control), 0.40 and 0.80 µm (sound-enamel roughness range), and 1.60 µm (initial-enamel caries-lesion roughness).[23]

For examiners' metal plaque's roughness blinding, these were covered with tape and only a 10 x 2 mm window was exposed for examination. Participated five experienced dentists and researchers working in the caries research unit (three with a MSc degree, one with a PhD degree and one conducting a PhD), all calibrated in the visual caries ICDAS criteria to perform caries assessments, and with experience of participating in training other dentist/researchers in the same diagnosis criteria.[24,25] Additionally, these examiners were standardized in the use of the WHO probe because the ICDAS assessment system includes the use of the WHO probe in order to evaluate the dental surfaces during the diagnosis. In that order of ideas, as the five examiners were calibrated in those criteria, all of them were standardized in the use of this probe as well. For this study, examiners needed to use the WHO probe for caries lesion and for activity assessment; therefore all of them attended a one hour training session to standardize the roughness-tactile assessment method. The roughness-tactile sensation was scored using a 4-point-modified Likert scale (1-Definitely smooth; 2-Smooth; 3-Rough; 4-Definitely rough). An external research assistant randomly assigned the instruments' (n = 5: 4 controlled-pressure probes; 1 WHO probe) and plaques' order (n = 4) before each exam. Examiners were instructed to perpendicularly-to-the-surface move the probe's tip left-to-right three times on the plaque's examination window and provide a roughness score.

Study on enamel surfaces

Two weeks later the diagnostic accuracy of the roughness perception using the pilot-study selected probe vs. the WHO control was carried out on human-enamel blocks obtained from sound-enamel permanent teeth (n = 20) from the teeth biobank in our institution. Twenty blocks of 4 x 2 x 4 mm (length x width x height) were obtained and randomly assigned to two groups of ten blocks each: sound (*S*) and demineralized (*D*). All surfaces -except for the enamel- were isolated with nail polish. The *D*-group blocks were subjected to 48-hour pH-cycling to produce artificial-caries lesions. Briefly, blocks were immersed in a demineralizing solution (15 h/37°C), washed (deionized water), dried (paper tissue) and immediately immersed in demineralizing solution (15 h/37°C) following Queiroz et al. protocol.[26] The demineralization reaction was interrupted with deionized water and the blocks immediately preserved in thymol (4°C). Blocks were then imbibed in acrylic translucid resin, exposing only the enamel surface. Surface roughness (Ra) was measured in triplicate in all enamel specimens using a contact roughness meter (SJ-401, Mitutoyo, Kanagawa, Japan). The order of both the instruments (n = 2: controlled-force probe; WHO probe). and the blocks (n = 20) were randomized. For the examination, examiners were instructed to perpendicularly-to-the-surface move the probe's tip left-to-right three times on the enamel surface and to provide a roughness score. The roughness-tactile sensation was scored using the same 4-point-modified Likert scale (1-Definitely smooth; 2-Smooth; 3-Rough; 4-Definitely rough). Two sessions were conducted with the interval of one day between them and for the second one, the specimens were reordered. The intra-examiner reliability was checked by comparing both evaluations.

The enamel-block examination followed the pilot-study methodology, randomly assigning the order of enamel blocks (n = 20) and instruments (n = 2: controlled-force probe; WHO probe).

Statistical analyses

Normality of the data was tested with the Kolmogorov-Smirnov and Levene tests. Surface roughness data from human-enamel blocks were log-transformed. The pilot-study standardized plaques were assigned a score on their ascending level of roughness.[1-4] The correlation among the examiner-roughness given Likert score and the plaque-roughness level was calculated with Spearman correlation coefficients. The pilot-study inter- and intra-examiners reproducibility were estimated with intra-class correlation coefficients (ICCs).

Inter- and intra-examiner reproducibility of the roughness evaluations performed on enamel blocks (controlled-pressure probe vs. WHO probe) were assessed using quadratic weighted-Kappa scores. Surface roughness (Ra), intra- and inter-examiner agreement weighted-Kappa scores were summarized with means and their 95% confidence intervals and comparisons were made using Student's t-tests.

Using the enamel blocks' group (*S* or *D)* as reference categories, overall specificity, sensitivity and accuracy were calculated for each instrument, and then separately for each instrument, examiner and assessment (1st or 2nd assessment). Multilevel Poisson models were generated to evaluate the influence on specificity, sensitivity and accuracy of the instrument, the examiner, assessment's order, the exam's sequence, and the enamel's roughness. For that, according to the reference, assessments were classified in true or false regarding the surface roughness. For sensitivity, we considered the percentage of truly rough surfaces detected (demineralized enamel blocks) while for specificity, the percentage of truly smooth surface detected (sound enamel blocks) were computed. Finally, the percentage of the correct roughness pattern (smooth or rough indiscriminately – sound + demineralized blocks) were considering when performance the overall accuracy analyses. Results for the association between each performance outcome and the independent variables are reported as Prevalence Ratios (PR) with 95% confidence intervals. Reproducibility, validity and comparison of means were performed with the software MedCalc 13.3.3.0 (Medcalc bvba, Mariarke, Belgium) and multilevel analyses were performed with Stata SE 13.0 (StataCorp LP, College Station, USA). Test statistics with a p-value < 0.05 were considered statistically significant.

Results

Pilot for the selection of the probe's design

The pilot study disclosed a strong correlation between the plaque-roughness levels and the examiner-roughness-assessment scores using each instrument (range of Spearman correlation coefficients (minimum – maximum) for novel designs: 0.70–1.0 and for WHO probe: 0.78–0.78). Regardless of the probe, the examiners were highly consistent between them, with inter-examiners' ICCs > 0.80 (Table 1). However, lower consistency was shown within their own examinations using each probe. The highest inter-examiner ICC was reached using the probes "B" and "D", whereas the highest intra-examiner ICC was reached with the WHO probe, followed by the probe "D". Thus, instrument "D" was selected for subsequent analyses (Figure), corresponding to the smallest handle's diameter, shortest tip-arm length, lowest handle's weight, and a rough and angled ball-ended tip in comparison to probes A-C (Table 2).

Study on enamel surfaces

The mean (SD) roughness (Ra) of sound-enamel (0.73; 95%CI: 0.58–0.88) and demineralized-enamel surfaces (1.34; 95%CI: 0.85–1.83) used was significantly different (p = 0.011). The examiners' agreement using the WHO in comparison to the controlled-pressure probe on the sound and carious enamel blocks was acceptable to good, showing respective mean of weighted-kappa scores: Inter-examiner first evaluation (0.44 ± 0.16 vs. 0.56 ± 0.10; p = 0.078) and second evaluation (0.51 ± 0.13 vs. 0.56 ± 0.10; p = 0.301); Intra-examiner (0.52 ± 0.17 vs. 0.67 ± 0.14; p = 0.304). Crude (unadjusted) sensitivity, specificity and accuracy values were higher for the controlled-

Table 1. Examiners' reproducibility using the different probes on standard roughness plaques.

Probe	Intra-examiner reproducibility		Inter-examiner reproducibility	
	ICC	95%CI	ICC	95%CI
A	0.45	0.28-0.93	0.87	0.50-0.99
B	0.25	-0.72-0.88	0.96	0.84-0.99
C	0.56	0.13-0.95	0.95	0.80-0.99
D	0.69	0.28-0.97	0.96	0.83-0.99
WHO	0.74	0.35-0.97	0.89	0.56-0.99

ICC: intra-class correlation coefficient; CI: 95% confidence interval.

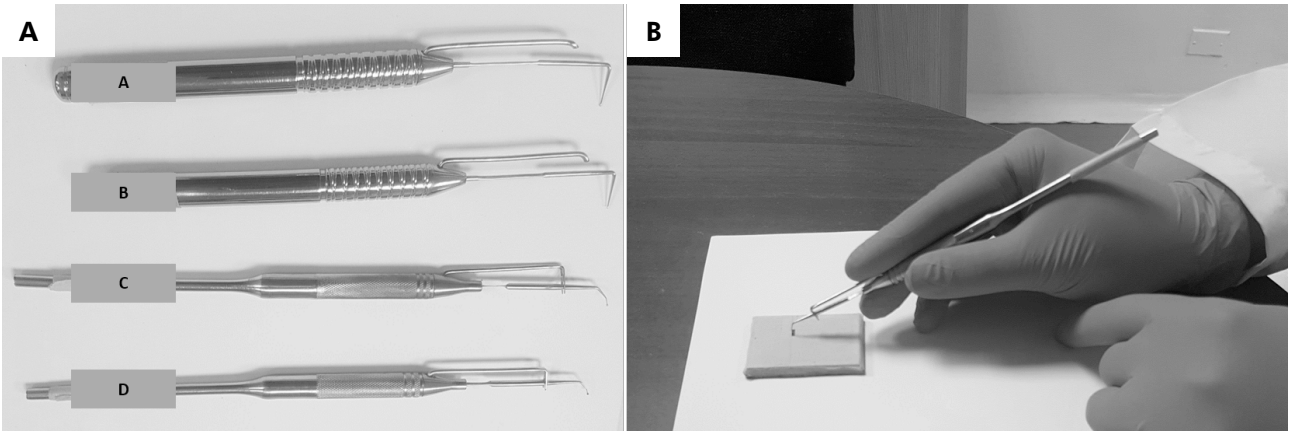

Figure. A – Controlled-pressure novel probes designs tested during the pilot. "D" probe was the one selected for the study on enamel surfaces. B – Examiner's position for the assessment of tactile perception of roughness on the standard roughness plaques. Source: Original

Table 2. Characteristics of the novel instruments designed for the study.

Probe	Probe weight	Handle diameter	Tip's arm length (mm)	Tip's roughness (μm)	Tip's arm angle
A	27	30	10	0	90°
B	55	30	10	0	90°
C	20	24	7	0	120°
D	18	24	7	12.5	120°

ICC: intra-class correlation coefficient; CI: 95% confidence interval.

Table 3. Influence of different variables on the specificity, sensitivity and accuracy during the assessment of the tactile perception of roughness.

Variable	Specificity	Sensitivity	Accuracy
	Unadjusted PR	Unadjusted PR	Unadjusted PR
	(95%CI)	(95%CI)	(95%CI)
Probe			
WHO	Reference	Reference	Reference
Controlled-pressure	1.07 (0.79-1.46)	1.05 (0.74-1.49)	1.07 (0.85-1.35)
Examiner			
1	Reference	Reference	Reference
2	0.84 (0.51 - 1.37)	2.13* (1.11 - 4.06)	1.19 (0.81 - 1.75)
3	0.82 (0.52 - 1.31)	2.00* (1.07 - 3.76)	1.15 (0.80 - 1.66)
4	0.78 (0.48 - 1.26)	2.05* (1.10 - 3.81)	1.13 (0.80 - 1.66)
5	0.92 (0.59 - 1.45)	2.12* (1.14 - 3.92)	1.25 (0.88 - 1.79)
Assessment			
First	Reference	Reference	Reference
Second	0.97 (0.71 - 1.31)	1.23 (0.87 - 1.74)	1.08 (0.85 - 1.35)
Exam's sequence	1.00 (0.99 - 1.01)	1.00 (0.99 - 1.01)	1.00 (0.99 - 1.01)
Enamel roughness	0.95 (0.44 - 2.07)	0.95 (0.62 - 1.44)	0.87 (0.70 - 1.08)

PR: prevalence ratios; *$p < 0.05$.

pressure probe (71.1%, 90.6%, 81.2%, respectively) compared to that of the WHO (67.4%, 84.6%, 75.8%, respectively). When the effect of: variables, examiner, assessment order, and roughness values were controlled for in multilevel Poisson models, sensitivity, specificity and accuracy prevalence ratios of the controlled-pressure probe remained higher ($p > 0.05$) (Table 3). There was a statistically significant association (PR: $p < 0.05$) between the examiner's roughness assessment and roughness sensitivity (percentage of rough enamel samples correctly identified as rough).

Discussion

Consistent with a previous report,[20] the results of this study confirm a strong correlation between roughness and the roughness-tactile perception. As with the WHO probe, examiners using the novel controlled-pressure probes had the ability to distinguish different roughness' levels in known-roughness values metal plaques. In contrast to a study that found a very low inter-examiner ICC value using the WHO probe (0.03)[20] our was high for both probes (WHO: 0.89; controlled-pressure probe: 0.96) in pilot study, when using the metal standards. This discrepancy might be explained by the high acquaintance of the examiners in the current study to probing for the roughness-tactile perception within the caries activity-status assessment.[4,10,2] Ekstrand et al.[10] reinforce the relevance of training dentists in order to identify differences between active and inactive caries lesions through visual/tactile examinations.

In the pilot study, the novel probe "D", depicted the highest intra-/inter-examiner ICC and was selected for subsequent comparisons with the WHO probe (Table 2/Figure 1).[11-13] This had a smaller handle's diameter, a shorter tip's length, a lower handle's weight, and a rough ball-ended tip in comparison to probes A-C, characteristics described by examiners as assessment facilitators.[21,22] When comparing roughness-tactile perception reliability and diagnostic accuracy measures between probes in sound surfaces and artificial-initial enamel-caries lesions, the novel probe displayed better sensitivity, specificity and accuracy. However, in crude comparisons it is difficult to separate the probe's effects from those of other variables that highly influence a tactile perception assessment of this nature. Further analyses conducted to control for the influence of such variables on the crude sensitivity, specificity and accuracy values (multilevel Poison models) revealed that the examiner remains the most important influencing factor ($p < 0.05$), with the novel controlled-force probe potentially aiding an examiner reaching higher diagnostic accuracy values.

The examiners who participated in this research manifested verbally smooth surfaces were easier to perceive using the novel probe. Material science research has concluded that during the roughness-tactile perception assessment of fairly smooth surfaces (*e.g.* enamel), the use of rigid probes relies on the vibrations perceived by the examiner, whereas for increasing roughness, the perception relies on the information on the spatial pressure distribution.[21] The low number of samples used (n=20) and using artificial instead of natural initial caries lesions are study limitations. However, observed trends in this preliminary study on initial-enamel caries lesions demonstrate that the roughness assessment resulted in high reliability and accuracy with both instruments[20].

The fact that the roughness-tactile perception has been associated with an active status in initial caries lesions[10,11,17] was what led us to design this study. While we were not able to demonstrate a significant higher accuracy and reproducibility of the novel probe, high related values were achieved with both instruments. These differ from the more traditional sharp probe in its tip shape (round vs. sharp), but also in the way the assessment is conducted. Previous studies have demonstrated that using a sharp probe to detect occlusal-surface caries lesions, considering the so-called "stickiness" characteristic as a caries lesion, produced an irreversible damage in the demineralized enamel,[27] with the ball-ended probes being less harmful for the examination of dental surfaces.[2728] Besides the tip end (ball-ended vs. sharp) another relevant aspect during the roughness assessment would be the pressure exerted, aspects that have changed with the caries paradigm shift, leading towards the detection and assessment of caries based on visual characteristics, with the aid of a ball-ended probe with a gentle probing.[6-8,18] The results of this study suggest that it is possible to accurately and consistently conduct this type of examination in the practice -assess roughness in initial caries lesions to help inform the activity status of the lesion, subject to properly training of examiners.

Authors hypothesize increasing training of examiners in the assessment of initial caries lesion's activity status in smooth surfaces by means of assessing roughness -with the WHO probe- may be an interesting alternative given the observed findings with trained examiners. Although enamel roughness is in fact a subjective parameter to be evaluated (moderate

values of reproducibility values observed), trained examiners involved in this study, when probing artificial caries presented high values of sensitivity. Besides, high values for specificity also proved they were able to correctly detect sound surfaces. Finally, we also have to consider the assessment of artificial lesions as a limitation. Since the lesion is quickly formed, their different patterns may be also interfered on repeatability of examinations by reasons already pointed out. Therefore, evaluating their reliability in clinical studies with natural initial caries lesions as well as translating this exam into the clinical practice are further important research steps.

Conclusion

Compared to the WHO probe, the inclusion of a pressure-control stopper into the design of a ball-ended probe did not significantly increase the intra-/inter-examiner agreement or the diagnostic accuracy among trained examiners. Instead, the pressure-controlled probe was comparable, with the examiner remaining the most important factor influencing diagnostic accuracy.

Acknowledgements

The authors want to acknowledge Dr. Luis Fernando Gamboa, from UNICA, Research Department, Universidad El Bosque, is acknowledged for his support with the statistics in the first part of the study. Drs. Murisi Pedroza and Isabella Louzada, Department of Paediatric Dentistry, School of Dentistry, Universidade de São Paulo, Brazil, are acknowledged for their technical help. Source(s) of support: This study was funded by Universidad El Bosque (PCI-2013-421) and Colciencias (Administrative Department of Science, Technology and Innovation, Colombia) (676-2014).

References

1. Ekstrand KR, Ricketts DN, Kidd EA. Reproducibility and accuracy of three methods for assessment of demineralization depth of the occlusal surface: an in vitro examination. Caries Res. 1997;31(3):224-31. https://doi.org/10.1159/000262404
2. Nyvad B, Fejerskov O. Assessing the stage of caries lesion activity on the basis of clinical and microbiological examination. Community Dent Oral Epidemiol. 1997 Feb;25(1):69-75. https://doi.org/10.1111/j.1600-0528.1997.tb00901.x
3. Ekstrand KR, Ricketts DN, Kidd EA, Qvist V, Schou S. Detection, diagnosing, monitoring and logical treatment of occlusal caries in relation to lesion activity and severity: an in vivo examination with histological validation. Caries Res. 1998;32(4):247-54. https://doi.org/10.1159/000016460
4. Ekstrand KR, Zero DT, Martignon S, Pitts NB. Lesion activity assessment. In: Pitts NB, editor. Detection, assessment, diagnosis and monitoring of caries. Basel: Karger; 2009. p. 63-90.
5. Neuhaus KW, Nyvad B, Lussi A, Jaruszewski L. Evaluation of perpendicular reflection intensity for assessment of caries lesion activity/inactivity. Caries Res. 2011;45(4):408-14. https://doi.org/10.1159/000330530
6. Pitts NB, Ekstrand KR. International Caries Detection and Assessment System (ICDAS) and its International Caries Classification and Management System (ICCMS) - methods for staging of the caries process and enabling dentists to manage caries. Community Dent Oral Epidemiol. 2013 Feb;41(1):e41-52. https://doi.org/10.1111/cdoe.12025
7. Pitts NB, Ismail AI, Martignon S, Ekstrand KR, Douglas GV, Longbottom C. ICCMSTM guide for practitioners and educators. London: King's Coll London; 2014 [cited 2020 Dec 10]. Available from: https://iccms-web.com/uploads/asset/592845add7ac8756944059.pdf
8. Martignon S, Pitts NB, Goffin G, Mazevet M, Douglas GV, Newton JT, et al. CariesCare practice guide: consensus on evidence into practice. Br Dent J. 2019 Sep;227(5):353-62. https://doi.org/10.1038/s41415-019-0678-8
9. Ekstrand KR, Martignon S. Visual-Tactile detection and assessment. In: Meyer-Lueckel H, editor. Caries management: science and clinical practice. Stuttgart: Thieme; 2013. p. 69-85.
10. Ekstrand KR, Ricketts DN, Longbottom C, Pitts NB. Visual and tactile assessment of arrested initial enamel carious lesions: an in vivo pilot study. Caries Res. 2005 May-Jun;39(3):173-7. https://doi.org/10.1159/000084794
11. Ekstrand KR, Martignon S, Ricketts DJ, Qvist V. Detection and activity assessment of primary coronal caries lesions: a methodologic study. Oper Dent. 2007 May-Jun;32(3):225-35. https://doi.org/10.2341/06-63
12. Ekstrand KR, Gimenez T, Ferreira FR, Mendes FM, Braga MM. The International Caries Detection and Assessment System - ICDAS: a systematic review. Caries Res. 2018;52(5):406-19. https://doi.org/10.1159/000486429

13. Nyvad B, Baelum V. Nyvad criteria for caries lesion activity and severity assessment: a validated approach for clinical management and research. Caries Res. 2018;52(5):397-405. https://doi.org/10.1159/000480522
14. Drancourt N, Roger-Leroi V, Martignon S, Jablonski-Momeni A, Pitts N, Doméjean S. Carious lesion activity assessment in clinical practice: a systematic review. Clin Oral Investig. 2019 Apr;23(4):1513-24. https://doi.org/10.1007/s00784-019-02839-7
15. Ferreira Zandoná A, Santiago E, Eckert GJ, Katz BP, Oliveira SP, Capin OR, et al. The natural history of dental caries lesions: a 4-year observational study. J Dent Res. 2012 Sep;91(9):841-6. https://doi.org/10.1177/0022034512455030
16. Thylstrup A, Bruun C, Holmen L. In vivo caries models: mechanisms for caries initiation and arrestment. Adv Dent Res. 1994 Jul;8(2):144-57. https://doi.org/10.1177/08959374940080020401
17. Nyvad B, Machiulskiene V, Baelum V. Reliability of a new caries diagnostic system differentiating between active and inactive caries lesions. Caries Res. 1999 Jul-Aug;33(4):252-60. https://doi.org/10.1159/000016526
18. International Caries Detection and Assessment System Coordinating Committee. Rationale and evidence for the International Caries Detection and Assessment System (ICDAS II). 2011 [cited 2020 Dec 10]. Available from: https://www.iccms-web.com/uploads/asset/592848be55d87564970232.pdf
19. Floriano I, Rocha ES, Matos R, Mattos-Silveira J, Ekstrand KR, Mendes FM, et al. How combining different caries lesions characteristics may be helpful in short-term caries progression prediction: model development on occlusal surfaces of primary teeth. BMC Oral Health. 2021 May;21(1):255. https://doi.org/10.1186/s12903-021-01568-2
20. Ando M, Eckert GJ, Zero DT. Preliminary study to establish a relationship between tactile sensation and surface roughness. Caries Res. 2010;44(1):24-8. https://doi.org/10.1159/000275570
21. Tiest WM. Tactual perception of material properties. Vision Res. 2010 Dec;50(24):2775-82. https://doi.org/10.1016/j.visres.2010.10.005
22. Kalkwarf KL, Kaldahl WB, Patil KD. Comparison of manual and pressure-controlled periodontal probing. J Periodontol. 1986 Aug;57(8):467-71. https://doi.org/10.1902/jop.1986.57.8.467
23. Zhang XZ, Anderson P, Dowker SE, Elliott JC. Optical profilometric study of changes in surface roughness of enamel during in vitro demineralization. Caries Res. 2000 Mar-Apr;34(2):164-74. https://doi.org/10.1159/000016585
24. ICCMS™ Caries Management. Core training elearing programme, ICDAS Calibration for ICCMS(TM) - Spanish. [cited 2022 May 4]. Available from: https://www.iccms-web.com/content/resources/elearning
25. Martignon S, Castiblanco G, Cortés A, Marín-Gallón L, Gómez S, Gómez O, et al. Reporte de una metodología de calibración de examinadores en el uso del Sistema Internacional de Detección y Valoración de Caries (ICDAS)/Report of a method for the calibration of examiners in the International Caries Detection and Assessment System. Univ Odontol. 2015;34(73):159-72. https://doi.org/10.11144/Javeriana.uo34-73.rmce.
26. Queiroz CS, Hara AT, Paes Leme AF, Cury JA. pH-cycling models to evaluate the effect of low fluoride dentifrice on enamel de- and remineralization. Braz Dent J. 2008;19(1):21-7. https://doi.org/10.1590/S0103-64402008000100004
27. Ekstrand K, Qvist V, Thylstrup A. Light microscope study of the effect of probing in occlusal surfaces. Caries Res. 1987;21(4):368-74. https://doi.org/10.1159/000261041
28. Mattos-Silveira J, Oliveira MM, Matos R, Moura-Netto C, Mendes FM, Braga MM. Do the ball-ended probe cause less damage than sharp explorers?-An ultrastructural analysis. BMC Oral Health. 2016 Mar;16(1):39. https://doi.org/10.1186/s12903-016-0197-9